Natural Regeneration of Three Oak Species at the Enid W. Pearson-Arastradero Preserve in Santa Clara County, California

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July 2008

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Report to be cited as follows:

Trulio, L.A., S. Aslanian, D. Carmichael, M. Esquivel, K. Gleeson G. Hurtado, M. Keasey, J. McRae, R. Ross, J. Sinclair, W. Thornton, A. Torres, and S. Woolhouse. 2008. Natural Regeneration of Three Oak Species at the Enid W. Pearson-Arastradero Preserve in Santa Clara County, California. Report to Sheri Lubin and Miriam Sachs-Martin, Acterra, Arastradero Preserve, Palo Alto, CA. 108pp.

EXECUTIVE SUMMARY

Since the late 1970s, restoration biologists have been examining the question of oak regeneration. In many areas of California, certain oak communities seem to be experiencing little or no tree replacement (Zavaleta et al. 2007). These populations have seasons of good acorn germination and seedling establishment, but there is a failure of seedlings to be “recruited” into the young tree phase. Natural communities that include blue oak, *Quercus douglasii,* and valley oak, *Q. lobata,* are reported to have some of the lowest regeneration rates (Pavlik et al. 1991). A recent study looking at long term oak regeneration, however, did suggest that low seedling survival rates of three California oak species corresponded with low rates of mature oak mortality (Tyler et al. 2006). This suggests that restoration practitioners must appropriately evaluate their individual restoration sites before developing an oak management strategy.

This study evaluated the natural regeneration rates of coast live (*Q. agrifolia*), blue and valley oaks at the Enid W. Pearson-Arastradero Preserve in the City of Palo Alto, Santa Clara County, CA. Used field data analyzed with geographic information systems (GIS) and statistical tests, we assessed these questions:

1) Are valley oak, blue oak, and coast live oak regenerating naturally at Arastradero and, if so, what are the characteristics of the saplings?
2) Is there a relationship between sapling qualities and a number of different local factors including the amount of canopy cover, amounts of different ground covers, numbers of gopher holes, and proximity of trees and shrubs?
3) Is an oak planting program needed at the Preserve and, if so, how and where should the oaks be planted to best ensure their survival?
4) What are our overall recommendations for future oak restoration at the Preserve?

We developed a sampling design based on that described by Sweicki et al. (1993), who examined factors that affected blue oak sapling recruitment and regeneration. They sampled 100 plots at 15 different sites within the blue oak range. We altered the study design to allow for sampling 3 oak species at one site. We also changed plot sampling protocol by sampling in a stratified random manner to assess the effect of cover and proximity to trees on sampling presence. Using an ArcGIS map of oak stands at Arastradero, we selected and sampled 10 oak

stands and 166 plots within those stands. Three stands were dominated by coast live oaks, 3 by blue oaks, and 4 by valley oaks.

We found saplings in 71 of the 166 plots, or 43% of plots sampled. Of the 166 plots, 24% contained live oak saplings (43/166 plots), 5% contained blue oak (8/166), and 11% contained valley oaks (20/166). Plots with coast live oaks were found equally in all three stand types. The 8 plots with blue oak seedlings were found only in blue and valley oak stands, while the 20 plots with valley oak seedlings occurred only in valley oak stands. Saplings of all three species were most likely to occur in the tree strata. Plots with live oak and valley oak saplings had much higher percentages of canopy, litter, and bare ground cover than plots without saplings; live oak plots also had much less grass cover. We measured 189 individual young oaks and found only 66 true saplings (>10 inches in height), 58 of which were live oaks, 5 were blue, and 3 were valley oaks. Only 6 plants were above browse height and all of these were live oaks. We measured 66 adult trees in our plots consisting of 34 live oaks, 8 blue oaks, 18 valley oaks, 5 California buckeyes, and 1 California bay. All were alive and only one tree, a live oak, appeared to be in poor health.

While plots with coast live oaks occurred in all 3 stands and strata, live oak saplings were much more likely to be found in the tree strata of live oak stands ($F_{4,\ 166} = 10.336$; $P < 0.000$) than elsewhere. Blue oaks were also more likely to be found in the tree strata of blue oak stands ($F_{4,166} = 3.11$; $P = 0.017$) than elsewhere. Plots with valley oaks occurred only in valley oak stands and were much more likely to be found in the tree strata versus adjacent or grassland strata ($F_{2,166}= 4.686$, $P = 0.011$). These results suggest the young plants germinated near their parent tree. The number of live oak saplings per plot was positively associated with canopy cover, number of shrubs, and number of trees per plot. The total number of saplings per plot also showed a positive association with litter cover and canopy cover.

True saplings (>10 inches tall) occurred in plots with fewer gopher holes ($\overline{x}$ = 11.3, SE = 1) compared to plots with small saplings ($\overline{x}$ = 7.8, SE = 1.2) and the percent of bare ground in plots with true saplings ($\overline{x}$ = 17%, SE = 2.2) was nearly double than that of plots with small saplings ($\overline{x}$ = 8%, SE = 1.6). True saplings were, on average, further from the nearest tree than small saplings (14.8 feet, SE = 1.7 versus 10.6, SE = 1.3).

These results show that, while that valley, blue and coast live oak acorns are germinating at Arastradero Preserve, the great majority of these plants were ≤10 inches tall and many were seedlings, i.e. growing directly from the acorn. Young oaks tend to have high mortality rates during their first two years; this mortality rate is especially high during the second year after depletion of all the acorns' nutrients (Pavlik et al. 1991). Saplings growing above browse height are much more likely to be recruited into tree stage; this is because they are less likely to be killed by drought, fire, and large grazers (Bernhardt and Swiecki 2001). Based on this information, it seems that very few if any valley and blue oak recruits are surviving to adult tree stage. Protecting naturally-occurring saplings until they are taller than browse height may help in regeneration.

Based on our findings and the literature, we suggest these actions to promote oak regeneration at Arastradero Preserve:

1) *Protect regenerating oaks*. We found many plots with newly or recently germinated oaks of all three species. These young plants will die or be eaten if not protected.
   - We found only 8 plots with blue oaks and 20 with valley oaks. We recommend all these plots be protected with above-ground and below-ground herbivore protection. When choices need to be made, protect the largest saplings first.
   - Protect some of the coast live oak plots with true saplings. Saplings greater than 60 inches in height do not need protection.
   - Clear away non-native grasses and leaving areas bare or areas covered with leaf litter may also promote survival.
   - Sample more of the Preserve to find more blue and valley oak seedlings and saplings that could be protected.
2) *Plant blue and valley oaks*. Planting blue and valley oaks can also add to the stock of potential future trees. Planting acorns (rather than seedlings) and protecting all plantings with above and below-ground herbivore protection are strongly recommended. These oaks should be planted adjacent to stands dominated by their species. Blue oaks thrive better with cover (~40%) than valley oaks, which need a more open canopy. Irrigation the first two years will benefit the plantings. Coast live oaks are doing well but require monitoring as they are at risk of Sudden Oak Death.
3) *Plan for change*. There is no doubt that diseases and climate change and other unpredicted assaults will challenge oaks in the future. Experiment with planting a range of oak ecotypes and planting them in regions that, in the future, may have conditions beneficial to oaks.

Remain in contact with researchers studying oaks and climate change for the most relevant information, experimental approaches, and management strategies.

4) *Conduct more studies*. Also needed to manage oaks well are studies of:
   a. Soil type and moisture conditions most beneficial to oak survival.
   b. Succession planting.
   c. Survivorship of local ecotypes.
   d. Effects of native grasses on sapling growth and survival.
   e. Effects of goat grazing on grassland diversity and oak regeneration.
   f. Age structure of the Arastradero tree population and recruitment needed to compensate for tree death and to increase the oak population.
   g. Oak regeneration and habitat conditions at other sites in the region.

INTRODUCTION

California's native oak communities boast some of the highest levels of biodiversity in the state, sheltering at least 5,000 invertebrates, 320 terrestrial vertebrates, and 2,000 vascular plants (Pavlik et al. 1991). These communities are very wide-spread, covering approximately 11% of the state. Oak ecosystems promote healthy watersheds by preventing erosion, regulating water flow, and improving water quality (Bernhardt and Swiecki 2001). Since the 1800s, California's human population has increased from 300,000 to over 33 million. This explosive growth, concurrent with the introduction of ranching and farming, has changed many of California's oak woodlands (Pavlik et al. 1991) and resulted in the loss of approximately 3-5 million acres of the original 10-12 million acres in California (Tyler, et al. 2006). Ecological pressures such as intensive cattle grazing, invasive grasses, lowered watered tables, urbanization, and deforestation continue to aid in the decline of oak communities (Johnson 2002). Global climate change adds an additional threat to the already fragmented oak landscape; a regional climate change model has predicted an over 50 percent decrease in suitable oak habitat for both valley oak and blue oak over the next 90 years (Kueppers et al. 2005). Since ecological stressors on oak ecosystems are not declining, it is now up to resource managers to preserve and restore California's oak communities.

Since the late 1970s, restoration biologists have been examining the question of oak regeneration. In many areas of the state, certain oak communities seem to be experiencing little or no tree replacement (Zavaleta et al. 2007). These populations have seasons of good acorn germination and seedling establishment, but there is a failure of seedlings to be "recruited" into the young tree phase. Natural communities that include blue oak, *Quercus douglasii,* and valley oak, *Q. lobata,* are reported to have some of the lowest regeneration rates (Pavlik et al. 1991). A recent study looking at long term oak regeneration, however, did suggest that low seedling survival rates of three California oak species corresponded with low rates of mature oak mortality (Tyler et al. 2006). This suggests that restoration practitioners must appropriately evaluate their individual restoration sites before developing a management strategy.

This study evaluated the natural regeneration rates of three native California oak species at the Enid Pearson-Arastradero Preserve in the City of Palo Alto, Santa Clara County, CA. The Arastradero Preserve is a 622-acre open space in the foothills of the Santa Cruz Mountains. The site is managed for native habitats with the help of the non-profit organization, Acterra. Historically, this site was used as an Ohlone Indian hunting ground; however, by the late 1700s, the land was part of the Rancho Corte Madera Spanish land grant. The property was used first for timber drayage from the foothills, and then later used for horse ranching. In 1969, the City of Palo Alto zoned Arastradero as an “open space”, which prevented the development of residential housing. In 1997, Palo Alto contracted with Acterra to run the day-to-day park operations of the Preserve (Acterra 2008).

The Preserve’s oak landscape has stands of blue, valley, and coast live oak (*Q. agrifolia*); these three species fill different ecosystem niches. The drought-tolerant blue oak can grow in shallow, unfertile, relatively dry soils. It has a rapidly growing root structure and a waxy-coat on its deciduous leaves; these adaptations help it to conserve water. The blue oak’s ability to endure a range of conditions has enabled it to dominate nearly half of all California’s oak landscape (Pavlik et al. 1991). Valley oak, the largest of all California oaks, is found near waterways or in areas with rich, loamy soil. Its deep taproot enables it to have a steady supply of water during dry summers. Habitat loss for valley oaks has been extensive due to development of floodplains and groundwater pumping. The coast live oak is highly drought tolerant, evergreen oak with thick, leathery, leaves (Pavlik et al. 1991) and it is common within 50 miles of the coast in Northern California. Sudden Oak Death, a hardwood disease, threatens mature strands of coast live oak (Sweicki and Bernhardt 2006).

For this study, we researched whether natural oak regeneration is occurring at Arastradero Preserve and, if so, what factors seem to be associated with sapling location. We developed a sampling design based on that described by Sweicki et al. (1993), who examined factors that affected blue oak sapling recruitment and regeneration. They sampled 100 plots at 15 different sites within the blue oak range. We altered the study design to allow for sampling 3 oak species at one location. We also changed plot sampling protocol by sampling in a stratified random manner to assess the effect of cover and proximity to trees on sampling presence. Using an ArcGIS map of oak stands at Arastradero, we selected 12 oak stands to sample based on relative abundance to a target oak species. Four strands were picked for each of the three oak species sampled.

We encountered some problems in sampling. One constraint was that some of the sites were inaccessible due vast amounts of poison ivy or extremely steep slopes. Ultimately, we sampled 10 of the 12 selected stands and could not include some randomly selected locations. However, we did sample enough sites to perform a meaningful statistical analysis. Since we studied only one location in the Santa Cruz Mountain foothills, we recommend sampling other locations to develop a more complete picture of oak regeneration in the region.

This study was designed with the specific goal of aiding Arastradero Preserve land managers in directing an oak restoration program. With information on natural oak regeneration, managers can decide if they need to protect naturally-growing seedlings, actively plants acorns of specific species, or allow nature to takes its course. The results of this study may also be useful to other preserves in the area where managers are undertaking oak planting programs.

This report begins by providing background on the three oak species studied and offers history of the Arastradero Preserve, all information useful in making management decisions. Afterward, we describe the study methods, results, and the meaning of our findings. Finally, we provide recommendations for oak management at Arastradero Preserve based on our findings.

VALLEY OAKS (*Quercus lobata*)

Valley oaks (*Quercus lobata*) grow in California's inland valleys. Endemic to California, the valley oak has an impressive stature that dominates the landscape. With deep roots, thick protective bark, and an abundance of noticeably lobed green leaves, this species is well adapted to California's mediterranean climate. Conserving valley oaks is a high priority for restorationists. Valley oak populations are decreasing as a result of clearing trees for agriculture and urbanization, altered soil conditions, wood harvesting, inhibition of fire regimes, the removal of natural predators, changes in the water tables, herbivory, and disease (Bernatchez and Smith 2008). These changes to the natural valley oak habitat make it a challenge for restorationists to find ways to restore and protect this unique species.

Range and Physical Appearance

Before technological humans severely altered the land, valley oaks were a distinctive sight in the California landscape. Lush forests of valley oaks existed broadly throughout the entire state. "Remnant patches of this habitat are found in the Sacramento Valley from Redding south, in the San Joaquin Valley to the Sierra Nevada foothills, in the Tehachapi Mountains, and in valleys of the Coast Range from Lake County to western Los Angeles County" (Ritter 2008)

(Figure 1). They are most commonly found in oak savannas, riparian forests and foothill woodlands. Valley oak woodland once covered about 256,000 acres around the delta of the Kaweah River *alone* (Jepson 1910), but now this area represents almost the entire valley oak woodland for the entire state of California.

European settlement has greatly reduced the extent of oak woodlands, which have been lost to urbanization, agricultural fields, vineyards, and grazing. For example, in the San Joaquin Valley, the valley oak woodland may have been reduced by as much as 95%. Based on population projections, Delphine et al. (2008) states that residential development will continue in valley oak dominated areas because more than 90% of the area is privately owned and less than 3% is in formally designated reserves. The physical landscape has been altered as well as the biotic factors. "Numerous plant and animal species have been irrevocably lost, while many non-indigenous plant and animal species have become so widespread that their eradication is impossible." Dams and over extraction of water have negatively altered historic water tables and flooding regimes, upon which valley oaks depend (Bernhardt and Swiecki 2001). Policies against fire suppression, beginning in the 1940s, changed the structure and fuel load in valley oak woodlands. Fire repression has caused pine and shrubs to invade valley oak savannas. Prescribed burning in these areas could be beneficial to limiting competition. Burns might also stimulate oak seedling recruitment as scrub jays, which bury acorns, have a marked preference for burn areas as acorn caching sites (Howard 1992).

Figure 1: Range of Valley Oaks in California

(http://bss.sfsu.edu/holzman/courses/Fall02%20projects/valley_oak.html)

Valley oaks are deciduous, shedding their leaves in the winter. The leaves have rounded deep lobes (Figure 2). One side of the leaf is green with a velvety texture. The other side is light green with a hint of grey. Its trunk is long and sturdy, and its branches extend outward in distorted waves. The dull brown bark has a tint of grey and is thick with deep creases (Figure 3). Young trees, 10 to 20 years old, grow erect and pole-like with spreading lower branches tapering to slender tops (Jepson 1910). Mature valley oaks grow to between 45 and 110 feet and live as long as 400 years (Ritter 2008). They are arguably one of the largest oak trees in North America (Pavlik et al. 1991).

Figure 2: Lobed leaves of Valley Oak

(http://images.google.com/imgres?imgurl=http://lh3.google.com/)

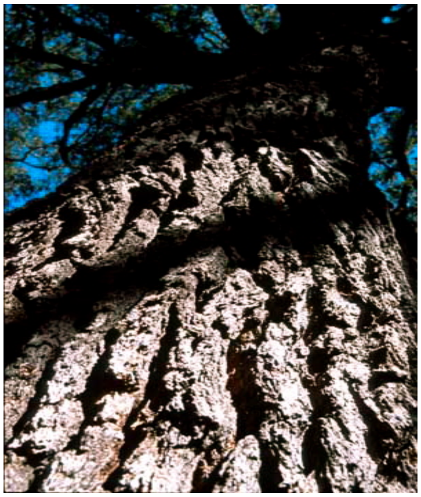

Figure 3: Bark of Valley Oak

(http://bss.sfsu.edu/holzman/courses/Fall02%20projects/valley_oak.html)

Physical Conditions

A reliable water source is critical for valley oaks. Their roots extend out and travel through fertile soil in search of water. This mechanism allows them to withstand droughts. They tolerate cooler wet winters as well as hot dry summers. They are also tolerant of underbrush and weeds, as well as mild floods and fire (Ritter 2008). They endure a variety of climatic and geographical zones because they extend over various latitudinal distributions (34 to 40˚ latitude) and elevation ranges (Delphine et al. 2008). Valley oaks prefer deep, rich bottomland soils at elevations below 2,000 feet, but may be distributed as high as 5,600 feet in as long as its roots can tap into a sufficient moisture source (Pavlik et al. 1991).

Valley oaks occur primarily in two plant communities, the valley oak woodland/savanna and the valley oak riparian forest (Pavlik et al. 1991). They are found in soils that are nutrient rich, often in sediments in floodplains. Historically, spring floods deposited thick layers of fine sand and clay that created loose, loamy soil. In these alluvial plains, there were plentiful sources of water saturated soil, nitrogen, and phosphorus, which supported rapid growth of individual trees (Pavlik et al. 1991). When valley oaks are not associated with a flood plain, they are generally found at sites with high soil moisture availability or a high water table and rarely ever at a steeper slope than 35 percent (Jepson 1910, Meyer 2002). When water tables drop, mature valley oaks experience higher than expected mortality rates (Brown and Davis 1991). Coastal valley oaks receive 20-80 inches of rain per year while inland populations receive 6-30 inches (Howard 1992) during the mild, wet winter. Long taproots enable valley oaks to have a constant supply of water during the hot, dry summer (Pavlik et al. 1991).

Growth Habits

Mature adult valley oaks disperse pollen, which travels by wind roughly 192 to 330 feet (Davis et al. 2005). Once successful pollination has occurred, acorns take approximately one year to develop (Pavlik et al. 1991). The warm summer days allow the acorns to become mature by September and November. Acorns are produced just before valley oaks lose their leaves in the winter. Small mammals, acorn woodpeckers, and other avian species help to disperse the acorns (Delphine et al. 2008). Buried acorns have a better chance of survival because it minimizes the likelihood of being eaten (Johnson et al. 2006). Next, the seedling begins to take root. Seedlings fare best in shade or on northern aspects of hills (Howard 1992). The growth of seedlings occurs underground where protection, water, and nutrients are available. After establishment, valley oak mortality may be highest in its second year of growth, which would correspond to time of complete carbohydrate depletion from the acorn (Bernhardt and Swiecki 1991). When the seedlings begin to bud, they can be considered a sapling. Once they emerge from the browse line, mortality rate lowers considerably (Howard 1992). The saplings can continue to grow even after it has been disturbed or browsed down.

Interactions with Other Important Species

Valley oaks provide important food and shelter for a wide range of animals. "The ranges of about 80 species of mammals in California show substantial overlap with the distribution of valley oaks, and several, such as fox and western gray squirrels and mule deer, have been documented using valley oaks for food and shelter" (Ritter 2008). Other species that aid in germination are the California ground squirrel (*Spermophilus beecheyi*), scrub jay (*Aphelocoma californica*), acorn woodpecker (*Melanerpes formicivorus)*, and yellow-billed magpie (*Pica nutalli*). The acorns are stored and hidden away for later consumption, yet not all the acorns are collected from their stored locations and many of them germinate. Acorn availability attributes to the reproductive success of the acorn woodpecker, western gray squirrel, bear, and deer (Johnson et al. 2006). Insects, rodents, and deer that inhabit oak woodlands are a staple food source for many predator species (Slack 2003). Valley oak savannas are also very important to migratory birds; healthy communities can harbor bird densities of 40 birds/ha (Howard 1992). This forest supports 67 nesting bird species including the state threatened Swainson's hawk (Howard 1992).

Smaller organisms that help the valley oak survive are mycorrhizal fungi. The oaks and mycorrhizae have a symbiotic relationship in which the mycorrhizae tap into the oak's root system to obtain nutrients and the mycorrhizae give the oak essential minerals and also help by protecting the oaks from disease (Meding and Zasoski 2008). The valley oaks promote one of the most biodiverse communities in California. It is common to see other plant species mixed with the valley oaks, such as the madrone (*Arbutus menziesii*), California bay (*Umbellularia californica*), Manzanita (*Arctostaphylos Manzanita*), and toyon (*Heteromeles arbutifolia*).

Decomposer species also play a significant role in the valley oaks ecosystem. Consumers such as insects, fungi, and bacteria decompose waste, which includes litter, dead plant matter, and feces. These decomposers are able manipulate the leftover nutrients from the ecosystem and renew the nutrients for plants to consume. The nutrient cycling relies on decomposers to function, and without them, the oak woodlands would not exist (Johnson et al. 2006).

For thousands of years, indigenous people also played a role in oak management. Native Americans burned oak woodland/savanna as a management tool; reasons for prescribed burns include stimulating growth of edible grasses, improving habitat for game animals, and killing insects that damaged acorn crops (Agee 1996). With rough bark and crown sprouting growths, valley oaks have adaptations to help them survive fire (Pavlik et al. 1991).

Factors in Regeneration

Valley oak populations are steadily declining. Currently, the regeneration of valley oaks is occurring at a very low rate (Fulfrost et al. 2007). Changing water regimes and widespread agricultural and residential development continue to threaten oak savanna (Pavlik et al. 1991). In Santa Ynez valley, there was a documented 21% decline in the number of mature oaks from 1938-1989; during the same time, there was no sapling recruitment in surveyed populations (Brown and Davis 1991). Restorationists are concerned about the combination of increased mortality and low levels of sapling recruitment. Although valley oaks seem to be the most prodigious acorn producer of all California oaks, very few seeds actually became trees (Jepson 1910). The Santa Barbara Oak Restoration Program reported that even in plots dominated by valley oak canopy, any naturally occurring oak seedlings tended to be blue or coast live oak (Mahall et al. 2005).

Many factors seem to contribute to low levels of valley oak sapling recruitment. Valley oaks are struggling to grow from seedling to sapling, and ultimately mature trees. One factor that may be inhibiting regeneration could be the competition with nonnative annual grasses and perennials for water. In valley oak savannas, perennial native grasslands have been largely replaced with Eurasian invasive grasses and weeds. These annuals grow rapidly during spring depleting available soil moisture. Since valley oaks rely on a moderate supply of water, a reduced level of soil moisture could inhibit regeneration. These annuals grow rapidly during spring, depleting available soil moisture. This reduced soil moisture reduces plant growth rate significantly (Danielsen and Halvorson 1991). For example, during dry years, seedling survival is much lower than years with abundant rainfall in winter (Tyler et al. 2002). Unfortunately, this trend in hotter drier season could be a result of global climate change. “Based on a regional climate change model, they predict that the range of valley oak will shrink to about 54% of its current distribution" (Delphine et al. 2008).

Cattle grazing has also been found to inhibit valley oak regeneration. For example, in valley oak savannas, bovine movements in rangeland increase soil compaction, making it harder for acorns to develop taproots. In areas where soil has been tilled, seedling survival is higher (Bernhardt and Swiecki 2001). Other threats to regeneration might include filbert weevil or filbertworm, which can prevent acorns from germinating. Canker rots and sulfur fungus both can cause internal decay of mature living oaks. Herbivorous predators are also very destructive to valley oak saplings. High non-native grasses could harbor more acorn and sapling consuming small mammals (Bernhardt and Swiecki 2001).

Restorationists can control certain physical factors to promote regeneration. Placing screens around seedlings can protect from predators such as mammals, insects and other disturbances. They can also provide moderate shade as well as weed control. Shorter native grasses can help sapling growth. Small herbivores like pocket gophers, mice, and ground squirrels have multiplied in the absence of mid-sized predators. In studies where seedlings have been protected from small herbivores by means of window screening or tree shelters, sapling emergence rates were twice as high (Tyler et al. 2002). This makes it apparent that successful establishment of valley oaks rely on protection from herbivores and grazers. Other easy, inexpensive means of improving seedling success include tilling soil before planting acorns and using mulch, which suppresses weed growth and conserves moisture at planting sites (Bernhardt and Swiecki 2001).

Restorationists can benefit from knowing exactly how to grow a valley oak from a seedling. Hobbs and Young (2001) have researched the success and failure of planting seedlings. "Two factors that play important roles in successfully growing woody plants are the size and overall quality of the seed and whether or not the seedlings are grown in containers" (Hobbs & Young 2001). Figure 4 shows valley oak acorns, even from the same tree are, not all equal in quality, which is a factor to consider in acorn selection. Acorn weevil larvae often leave holes in the shell of the acorn. This can cause negative effects on the growth of the shoot and root. Cracked seeds can cause the acorn to become dehydrated and become vulnerable to infections. Container size and acorn size play a role in the germination, growth rate, and survivorship of the valley oaks. Hobbs and Young (2001) found that one should pay close attention to not allow the tap to hit the bottom. They found "when seedlings were transplanted into larger pots, their shoot growth was four times greater than that of non-transplanted seedlings" (Hobbs & Young 2001). They also found that larger seeds germinate earlier and at higher rates.

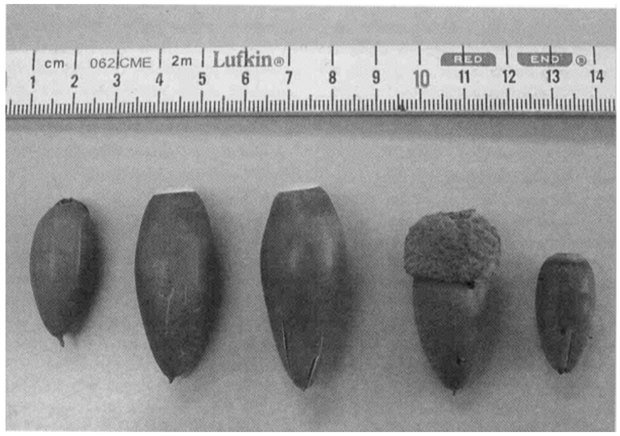

Figure 4: Valley Oak Acorns

(http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=5084604&loginpage=login.asp&site=ehost-live)

BLUE OAK (*Quercus douglasii*)

Range and Physical Appearance

The blue oak (*Quercus douglasii*) is endemic to California and is California's most widely-distributed hardwood (Swiecki et al. 1993). Historically, oak woodlands covered approximately 10 to 12 million acres in California (Johnson 2002). However, due to clearing for ranches, farms and development, this area has been decreased by 3-4 million acres (McCreary 2004 and Pavlik et al. 1991). Today 2,991,000 acres of blue oak woodlands remain (Swiecki et al. 1993). Blue oaks are present from Riverside County in the South to Del Norte County in the North (Figure 5) at elevations ranging from 460 to 1,200 meters (Swieki et al. 1993).

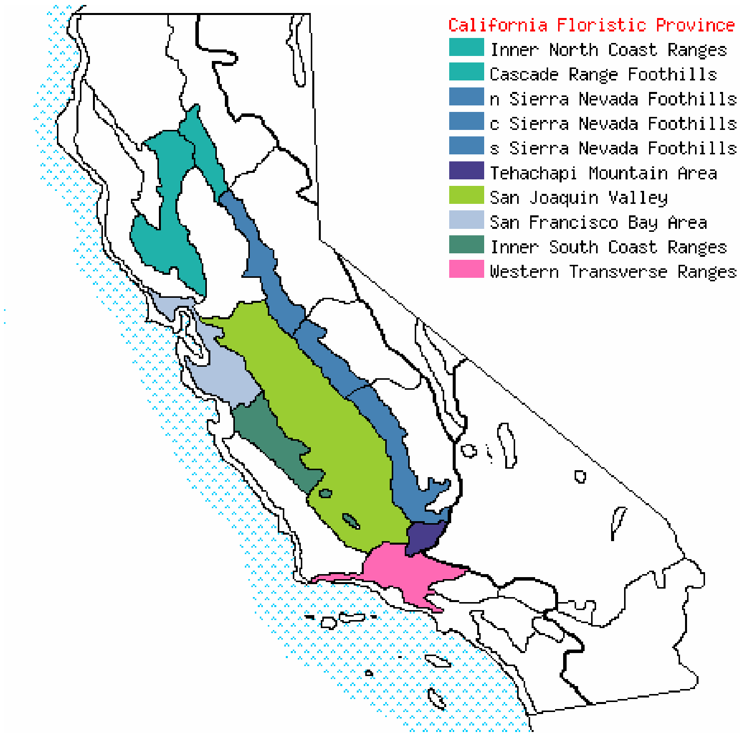

Figure 5: Distribution of Blue Oaks (Jepson and Berkeley 2000)

Blue oaks are found between valley grassland and coniferous forests in woodlands and savannas. Blue oaks occur with foothill pine (*Pinus sabiniana*), interior live oak (*Quercus wislizenii*), valley oak (*Quercus lobata*), and/or coast live oak (*Quercus agrifolia*). Blue oak woodland understory species can include poison-oak (*Toxicodendron diversilobum*), California coffeeberry (*Rhamnus californica*), bouckbrush (*Ceanothus cuneatus*), redberry (*Rhamnus crocea*), California buckeye (*Aesculus californica*), and manzanita (*Arctostaphylos disambiguation*) (Ritter n.d.).

A mature blue oak grows from 20 to 65 feet tall. The trees have grayish and checkered bark which is slightly scaly (Figure 6). Blue oaks can be distinguished by their bluish-green leaves which have lighter coloration on the underside. Blue oak leaves are lobbed, but less deeply than the valley oaks (*Quercus lobata*)(Figure 7). Another distinguishing characteristic is their dense, rounded crown.

Figure 6: Blue oak bark (http://www.birdmom.net)

Figure 7: Blue oak leaves (http://calphotos.berkeley.edu)

Growth and Physical Conditions

Blue oaks are slow growing trees (Vest 1999) that live from 175 to 450 years (IHMP 2000). They flower from the end of March to the middle of May depending on the climate and elevation. Warmer temperatures, present at hotter climates and lower elevations, will cause blue oaks to flower earlier. Blue oaks are capable of masting, i.e., producing a vast quantity of seeds in one season. Blue oaks mast approximately every three years (Fryer 2007), but only if conditions are favorable. Masting requires warm weather in April and hot summer months. The acorns germinate in the fall and the saplings have leaves their entire first year (Callaway 1992). Blue oak acorns weigh from 2 to 12 grams (Pavik et al. 1991). Acorn size effects early seedling growth. Larger acorns generally produce taller seedlings, more developed root systems, and have increased seedling survival (McCreary and Tecklin 1991), probably due the greater quantities or nutrients larger acorns are able to store. During the first years of growth, approximately 73% a seedling/sapling's weight is found at the root and 27% is found at the shoot (McDonald 1999). This indicates that a solid root system is important for proper nutrient uptake before shoot growth can occur. Root systems also serve as an important storage function for increased re-sprouting and survival.

Blue oaks are the most drought tolerant California deciduous oak species (Fryer 2007). Adaptations to drought conditions include thick leaves, which prevent water loss, and an ability to drop leaves and become dormant (Vest 1999). They also have the ability to alter their early root development, directing young roots towards the most abundant water location (Fryer 2007). Blue oaks live in Mediterranean climates, which have approximately 20 to 40 inches inches of precipitation annually (Ritter n.d.). They prefer temperatures from 75 to 96^{o} F in the summer and 29 to 42^{o} F in the winter (Ritter n.d.).

Soils samples under oak canopies indicated enhanced soil solution concentrations of Ca, Mg, K, SO_4, and PO_4 and decreased levels of Na compared to soil samples at non-oak sites (Dahlgren and Singer 1991). Levels of nutrients can greatly enhance the survival of a tree. The soil pH also was also 0.5-1.0 units higher under oak canopies compared to nearby grasslands (Dahlgren et al. 1991). The increase in pH is believed to be due to the neutralization of rainfall acidity by the oak canopy along with the increase in base action cycling (Dahlgren et al. 1991). This pH change was illustrated with blue oak when pH increased from 5.6 to 6.2 with the interaction between the canopy and precipitation (Dahlgren et al. 1991). Blue oak in particular had higher K levels and expelled more NH_4 than other oak species. Soil samples varied throughout the seasons. Pollution causes increased concentrations of NO_3 and PO_4 (Dahlgren et al. 1991).

Population

Genetic diversity is also an important factor in ensuring blue oak survival. Water availability greatly affects seedling recruitment and this sensitivity to competition for soil water may have a genetic component (Gordon and Rice 1991). Eliminating competing species will increase the survival rate of blue oak seedlings however some species may help blue oak survive. Blue oaks are capable of hybridizing with white oak trees (*Quercus alba*) including valley oaks (*Quercus lobata*), Oregon white oak (*Quercus garryana*), California scrub oak (*Quercus berberidifolia*), and turbinella oak (*Quercus turbinella*) (Pavlik et al. 1991). These hybrids are usually fertile and cytologically normal. Delany et al. (1991) ware able to distinguish the genetic variation between California oaks and to show that blue oaks are twice as variable within populations as compared to coast live and valley oaks (Delany et al. 1991).   Delany et al. (1991)

also demonstrated that there was "…no detectable geographic pattern in allozyme variation in any of the species and no indication of racial or subspecific variation."

Interactions with Other Important Species

Blue oaks play an important role in the ecosystem as they are a food source for many animals (Momen et al. 1994). Acorn woodpeckers (*Melanerpes formicivorus*), pocket gophers (*Thomomys bottae*), deer mice (*Peromyscus* spp.), black bears (*Ursus americanus*), California ground squirrels (*Spermophilus beecheyi*) black-tailed deer (*Odocoileus hemionus*), and scrub jays (*Aphelocoma californica*) all depend on blue oaks for food (Anderson 2003), and in turn these animals play an important role in distributing blue oak acorns (Fryer 2007). In addition to food, blue oak woodlands provide optimum breeding habitat for 29 species of amphibians and reptiles, 57 species of birds, and 10 species of mammals (Ritter n.d.). Blue oaks also sequester carbon dioxide and prevent soil erosion (Swiecki et al. 1993).

Blue oaks are susceptible to certain fungi, insects, and parasites. Although they are immune to sudden oak death, blue oaks are vulnerable to a fungus that causes their heart and root to rot. The presence and amount of wood decay varies by area, but this fungus has been known to infect up to 43% of a blue oak woodland with at least 20% wood decay (Arnold et al. 1991). Pacific mistletoe (*Phordendron villosum*), a parasite, has also been known to grow on blue oaks, but the impact of this species appears to be minor (Arnold et al. 1991). Insects such as cynipid wasps, filbert weevils (*Curculio uniformis*), ground-dwelling beetles, and filbert worms *(Melissopus latiferreanus)* all attack blue oaks. However, their impact is not significant (Arnold et. al 1991).

Blue oaks provided food and materials for California's indigenous populations. Native Americans mixed blue oak acorns with black oak (*Quercus. kelloggi*) acorns to produce soup, paddies, and bread (Anderson 2003). They used the inner bark of blue oak to brew a tea that helped relieve arthritis. The shoots of blue oaks were used to make baskets and other tools. Because of the importance of blue oak shoots, Native Americans would regularly use low intensity fires to increase their number (Anderson 2003).

Factors in Regeneration

The regeneration rate of blue oaks has been alarmingly low. Approximately half of existing blue oak woodlands are lacking blue oak saplings (Swiecki et al. 1993). The majority of blue oak trees today are over 120 years old (Mensing 1991). Swiecki et al. (1993) state that "current levels of recruitment are insufficient to offset current levels of mortality."

The presence of shade promotes blue oak regeneration, because the coolness protects against excessive dehydration and transpiration (Adams et al. 1992). In particular, blue oaks prefer partially shaded conditions. According to Swiecki et al. (1993), plots that are partially covered by canopy had a higher density of saplings than plots that had a high or low density of canopy cover in their study of numerous sites in Northern California. Shrubs also offer shade for blue oak saplings. Callaway (1992) confirms that blue oak saplings are also often found under shrubs such as California sagebrush (*Artemisa californica*) and purple sage (*Salvia leucophylla*). Implementing protective screens around young oaks increases their survival because the screen provides some shade and decreases access to herbivores (Adams et al. 1992).

According to Swiecki et al. (1993), although partial shade is beneficial to blue oak regeneration, blue oak saplings were found at a higher rate in the open than under canopy. Areas that were recently logged were more likely to support blue oaks. Blue oak saplings at the Pinnacles National Monument were often found next to dead trees where there was a canopy gap. However, blue oaks do not regenerate well if there is no blue oak canopy nearby. "Blue oak litter increases soil nutrients, organic material, friability, water holding capacity and creates a more equitable soil temperature regime (Holland 1973 and Callaway 1992)."

Floods and fires also contribute to successful regeneration. A fire or flood prior to acorn dispersal lowers the number of acorn predators. Floods kill ground-dwelling insects that eat the blue oak while fires kill ground-dwelling beetles which harm blue oaks (Fryer 2007). In addition, fires stimulate seedling to re-sprout and increases the growth numbers (Gordon and Rice 2000).

Mesic conditions (moderately moist conditions) favor blue oak regeneration. Swiecki et al. (1993) discovered that recruitment occurred more often in mesic locations. Seedlings do well at temperatures between 33 and 40 degrees (Anderson 2003). Soil moisture in blue oak seedling survival suggests that too much moisture greatly inhibits seedling growth (Kraus and Plumb 1991). In xeric locations, where there is not a lot of moisture, saplings were found on the more mesic plots. However, in really mesic locations, such as along riverbeds or lakes, other canopy species outcompete blue oaks.

Elevation also factors into the successful recruitment of blue oak saplings. Swiecki et al. (1993) found that blue oaks occurred more frequently at lower elevations within their range. The sapling that sprouted at lower elevations were also slightly more likely to survive than sapling located at higher elevations. There was a 83% survival rate for low elevations and 72% survival at high elevations. Blue oaks saplings appear to favor northerly aspects (Swiecki et al. 1993).

Planting may be needed to increase oak populations. If planting is used, acorns should be picked from different sites to allow for distinct genetic diversity and adaptation to the different conditions. Planting seedlings in May also greatly enhances chance of survival because it is early enough for them to grow and prepare for the summer dry months (Adams et al. 1991). Blue oak acorns tend to do best when planted at a depth of 2 inches (5.1cm) and putting 3 acorns per site greatly enhances their chance of survival (Honig et al. 1991).

Many factors can prevent blue oak seedling recruitment. Swiecki et al. (1993) claim that "regeneration can be inhibited by factors that deplete the reserve of persistent seedlings in the understory, inhibit the transition from seedling to sapling, or prevent saplings from advancing to the tree state." In order to encourage regeneration, these issues need to be addressed. Non-native grasses seem to hinder the regeneration of blue oaks, as they use more water than native perennial grasses (Gordon and Rice 2000, Swiecki et al. 1993), limiting the soil moisture available for blue oaks (Koukoura and Menke 1995). Annual grasses also hinder blue oak saplings from developing an adequate root system. Weed control has become necessary to allow seedlings to survive (Hannah and Plumb 1991).

Acorn predators and herbivores greatly limit the regeneration of blue oaks. Cattle and above ground grazers eat the leaves of young saplings (Fryer 2007). With no leaves to photosynthesize, saplings die. In areas with intense aboveground grazing, blue oak saplings were more likely to grow on steep slopes and between rocks where they hard to reach (Swiecki et al. 1993). The damage from cattle grazing can be limited by only allowing grazing during the month of January. According to Adams et al. (1991), grazing in January only damages 34% of blue oak seedlings, which allowed some blue oaks to regenerate. Underground herbivores, such as pocket gophers are just as harmful as above ground predators. They kill blue oak saplings by chewing near the root base (Fryer 2007). There is evidence of an increase in small animal populations whose feed primarily on blue oak seedlings. This increase may be due to an abundance of annual grasses and a decrease in small animal predators (Rossi 1980).

Fire suppression also suppresses blue oak regeneration. Historically, fires naturally occurred in California every 20 to 50 years, and these blazes had a positive effect on blue oak regrowth. However, since the 20th century, these fires have been suppressed (McCreary 2004).

Oaks that grow near urban settings face various environmental stresses that suppresses oxygen uptake (Costello 1991). Roots need oxygen for growth and survival, and oxygen occurs in higher concentrations near the surface of the soil, decreasing with depth. Oxygen can seep through pores within the soil; however, when the soil is compacted, oxygen has a difficult time traveling and cannot reach the roots. Human impacts such as construction, landscaping and domesticated livestock grazing all compact the soil and alter the uptake of oxygen by the roots. Too much water can also prevent oxygen from traveling through the pores within the soil. Of the oak species, blue oak is the least tolerant to low concentrations of oxygen. Blue oak roots function most efficiently at oxygen levels around 21% in order to avoid hypoxia (Costello 1991).

COAST LIVE OAK (*Quercus agrifolia*)

Range and Physical Conditions

The distribution of the coast live oak (*Quercus agrifolia*) stretches from Mendocino County to northern Baja California. It is "the most characteristic tree of California's coastal plains, valleys, and foothills (Pavlik et al. 1991)." The distribution extends approximately 50 miles-inland from the ocean to the San Francisco Bay and inner Coast Ranges on the east (Pavlik et al. 1991). *Quercus agrifolia* dominates foothill woodlands and mixed evergreen forests and is found in elevations less than 1500 meters in the coastal ranges and central California (Griffin 1973). Oaks of this genus are common to Mediterranean climates characterized by mild wet winters and summers with very little precipitation or variation in the overall temperature (Barret & Waddell 2005).

Quercus agrifolia grow on bluffs, gentle slopes, and canyons where there is well-drained soil (USDA NRCS 2003). In northern California, they can be found at elevations less than 3000 feet and in southern California at elevations above 5000 feet (IHRMP 2000). These trees are tolerant of different types of soils such as serpentine, silts, clays, and weathered granite, but cannot survive where the ground freezes. Although they are able to handle other types of soils "low-elevation coastal populations of coast live oak generally grow in loam, while higher-elevation coastal populations are associated with shaley clay-loam soil (USDA Forest Service

2002)." Coast live oaks also grow inland on sandy soils and in southern California islands where they grow on clay or clayey loam (USDA Forest Service 2002).

Quercus agrifolia is an evergreen and drought resistant tree native to California (Pavlik et al. 1991). These trees generally grow between 20 to 40 feet tall but some can reach up above 80 feet (IHRMP 2000). Coast live oak stands are made up of trees that are generally 40-110 years old and have diameters at breast height (DBH) ranging from 1-4 feet (IHRMP 2000, USDA Forest Service 2002). Some individual trees can live over 250 years (USDA Forest Service 2002). The leaves of a coast live oak are thick, leathery and oval and are 1 to 3 inches in length. They are also cupped and on the top portion of the leaf they look dark green and shiny while on the bottom they are fuzzy and gray in color (Figure 8)(IHRMP 2000, Virginia Tech 2008).

Figure 8: Coast Live Oak leaves

Coast live oaks acorns have cups at the top that have thin, flat scales. The one-seeded nuts are long and narrow with a length 0.75 to 2.75 inches (Figure 9). These acorns mature in one year (USDA NRCS 2003).

Figure 9: Coast live oak acorns

When growing in an open area, coast live oaks will often have large, thick canopies with foliage that sometimes goes to the ground. In more dense patches of oak woodland the coast live oak has irregular canopies and fewer branches lower on the trunk. Younger coast live oaks have smooth, gray-brown bark while the more mature oaks have developed furrowed and rigid gray bark that has a thickness of about 8 to 9% of bole or branch diameter (USDA Forest Service 2002). The trunk will sometimes grow into divided erect limbs, but more often will grow into crooked, wide-spreading limbs that touch the ground at times (Pavlik et al. 1991).

One unique quality of coast live oaks is their complex root system that has evolved to include a tap root. This tap root allows the oak tree to reach water far below the surface during times of drought when they otherwise would not be able to (Plumb and Gomez 1983). This tap root allows the saplings to establish themselves in the soil without exerting large amounts of energy to grow vertical (Plumb and Gomez 1983). Also because of their ability to establish the tap root when sprouting, they are able to grow on many north-facing slopes, ravines and even valleys where low water accessibility might inhibit other oak varieties (Cal Poly Lands 1983).

Quercus agrifolia are wind pollinated and are monoecious with staminate flowers and clustered postillate flowers. Acorn production is variable from year to year and there can be consecutively large crops followed by crop failures. Coast live oaks, however, are very productive relative to other California oak species (USDA Forest Service 2002). The acorns have no dormancy period and establish in dryer locations relative to other oak species. California oak species also show synchronized acorn production (masting) (USDA Forest Service 2002). There have been several hypotheses proposed for the synchronicity of California oak acorn production include:

1) Predator satiation – the abundance of acorns overwhelms potential acorn predators they become so satiated that some acorns are allowed to escape predation and go to seed.

2) Environmental cues (resource matching)-the environmental conditions over a geographic area are similar for all oaks in that area, allowing for the majority of the oaks in that area to receive the same environmental cues. These cues indicate to the oaks that current conditions are right for acorn production.

3) Rainfall-the amount of rainfall in previous years primes oaks for acorn production.

4) Attracting seed dispersers-oaks produce enough acorns to pay off dispersers with a high quality food and for disperser to cache acorns and miss some acorns when retrieving the cache later allowing some of these cached acorns to go to seed (USDA Forest Service 2002, Koenig at al. 1994).

As an adaptation to prevent seed loss to birds and small mammals, coast live oaks retain their acorns longer than other California oaks. Most acorns are dropped in the fall but some are left over and dropped in the spring (USDA Forest Service 2002). A study done by Matsuda and McBride (1989) showed that *Quercus agrifolia* had a slow germination process that starts later than other oaks and lasts longer. The initial stages of the slow growth process are made up mostly of the large taproot growing (USDA Forest Service 2002). This slower process can be explained mostly by variation occurring within acorns. In the same study the shoots for *Quercus agrifolia* developed in late November-January at the lowest elevation and in January-February at the highest elevation. Although it germinated slower than other oaks the mean germination rates of the coast live oak were much higher than other oak species (Matsuda and McBride 1989). Coast live oaks grow in the winter in order to avoid droughts and leaves grow from February to April. Flowering and fruit production of coast live oak is brought on by warm temperatures and usually occurs in the spring during stem elongation. In ideal conditions, such as in a green house, *Quercus agrifolia* seedlings have grown to 5-8 feet in 2 years (USDA Forest Service 2002).

<u>Interactions with Other Important Species</u>

Coast live oaks have many symbiotic relationships with plants and animals. Because of the interaction with neighboring grasslands, a number of understory plants like the native California Blackberry (*Rubus ursinus*), Western Poison Oak (*Toxicodendron diversilobum*) and Coyote Brush (*Baccharis pilularis*) have blossomed (Gordon 2001). Mycorrhizal fungi are very important to *Quercus agrifolia* in the uptake and transport of nutrients and water. This type of fungus acts as an extension to plant roots and can help the plant get water and nutrients during periods when the fertile upper soil is dry (Allen et al. 2002).

Oaks and animals also have important interactions with each other. There are several birds that depend on the acorns as a source of food. Birds such as the acorn woodpecker (*Melanerpes formicivorus*), yellow-billed magpie (*Pica nuttalli*), and scrub jay (*Aphelocoma* *californica*) all use coast live oak as a source for acorns. Squirrels also rely on acorns as a food source and store large numbers of acorns in the ground. Mice store some but mainly forage off of other storages. Both the birds and the small mammals that rely on the Coast live oak acorns as a source for food also act as acorn dispersers for the tree helps increase the population and distribution of the oak trees. They also protect acorns from being eaten by animals such as the black-tailed deer that generally cannot eat the acorns if they are buried in the ground (Griffin 1971).

Coast live oaks were used by indigenous peoples for many different purposes and for this reason the trees and surrounding land was managed. The acorns of the coast live oak were an extremely important food supply along parts of central and southern coastal California. Fallen tree limbs provided a source of wood used for cooking many foods and also as a source of warmth when burned because the wood burns hot and helps the coals retain heat for a longer time. Indigenous peoples also used oaks in general for basketry, regalia, household utensils, structures, tools, weapons, and as a source for medicine (Anderson 2007). This tree provided many uses and indigenous people greatly affected its ecology. The indigenous people saw the trees as a form of protection from invasion by other tribes. They would do so by sweeping the ground around the trees to keep the brush from becoming ladder fuels which would destroy their resource. They also pruned the trees and practice light, frequent burning. This would help establish spread out, large canopied trees that survived longer (Anderson 2007).

Factors in Regeneration

Several factors appear to be limiting oak regeneration and causing difficulties for restoration efforts. These factors include predation, grazing, competition with non-native species, habitat loss and alteration, human use, and disease.

Predation on acorns has been noted as a major source of seedling mortality in some oak species (Tyler et al. 2006). Although small animals and birds can help the population by distributing acorns they can also inhibit the growth of a population. Coast live oaks have varying acorn productions in different years and if there is a low supply of acorns one year and the animals eat all of them that would hurt the population of coast live oaks. “The increase in small mammal populations is likely due to an abundance of annual grass seeds and roots and a reduction of predators (Plumb and Hannah 1991).” Another form of predation comes from insects. Tyler et al. (2006) found insect damage in ground collected acorns at 71%-96% and 5%-29% in tree collected acorns. Coast live oaks are not only affected by animals above ground but they are also affected underground with root damage by animals such as gophers.

Livestock grazing has been directly implicated in the low recruitment rate of oaks in California due to soil compaction and herbivory on oak seedlings and saplings (Bernhardt and Swiecki 2001, Tyler et al. 2002, Tyler et al. 2006, USDA Forest Service 2002). However, the Forest Service suggests that, in some cases, livestock grazing can aid in the recruitment of oaks by suppressing the growth of herbaceous vegetation and exotic grasses and that the timing and intensity of livestock grazing may be a factor that influences oak recruitment (USDA 2002). Herbivory by native species, such as deer, has also been implicated in the high mortality of some species of oak seedlings, although *Q. agrifolia* has not been shown to be as heavily impacted by deer herbivory as other oak species (Bernhardt and Swiecki 2001).

Native California grasslands such as perennial bunchgrass (*Elymus glaucus*), nodding needlegrass (*Nassella cernua*), and purple needlegrass (*Nassella pulchra*) have been largely replaced by exotic non-native European grasses, such as slender hairgrass (*Deschampsia elongate*) (Gordon 2001). Coast live oaks and other native oak species must compete with exotic weeds and grasses for water, light, and nutrients (Plumb and Hannah 1991). Non-natives also have a tendency to dry up during the summer months and have resulted in fire hazards for the oak woodlands. This is attributed also to the carbon buildup, combined with forestry practices that believe in reducing fires which have proven to be disastrous in terms of California oak regeneration. Oak regeneration can also be affected negatively by periods of drought or moisture stress (Adams et al. 1992, Plumb and Hannah 1991).

The loss of habitat via urbanization and conversion to agriculture are direct losses to oak populations. Direct habitat loss causes the removal of reproductive oaks from the population, the removal of seed banks, the potential decline in genetic viability and the loss of suitable oak habitat (Bernhardt and Swiecki 2001, Tyler et al. 2006). Habitat fragmentation may contribute to the low recruitment rate in some oak species. It is possible that some oaks are density dependent with regards to wind pollination. The isolation of individuals into small populations may effectively decrease recruitment by limiting pollination in these populations and may contribute to the decline of genetic diversity in oak stands (Beals and Dodd 2006, Tyler et al. 2006).

Human use also has an impact on the coast live oak. *Q. agrifolia* is commercially harvested for firewood. Pillsbury et al. (2002) conducted a 12 year *Q. agrifolia* thinning study that indicated that thinned stands grew larger in diameter than unthinned stands. This study also indicated that thinned stands may fair better in forest fires. Pillsbury et al. (2002) also found that regeneration from stumps of harvested *Q. agrifolia* (coppice management) was extremely slow (this was attributed to grazing by livestock and wildlife). Pillsbury et al. (2002) recommended that harvested stumps should be protected from grazing to allow re-sprouting and increase regeneration time from stumps.

Sudden oak death (SOD) is a deadly disease that affects oaks such as *Quercus agrifolia* and tanoaks from Monterey to Humboldt County. The SOD pathogen is extremely time-consuming to identify. SOD is considered to have reached epidemic proportions in California. As of 2004 SOD has been found in 13 California counties (Guo et al. 2005). SOD is predicted to continue to spread into areas that are not currently infected, especially along coastal areas (Kelly and Tuxen 2003, Guo et al. 2005). This disease can cause bleeding, infestation by scolytid beetles, and the establishment of fruiting structures of the fungus *Hypoxylon thouarsianum* (McPherson et al. 2005). Sudden oak death can also lead to changes in the composition of the species in the infected forests, reduction in ecosystem functionality, losses by wildlife in terms of food, and changes in fire frequency because of rotting trees that become a fire hazard. A study by McPherson et al. (2005) showed that there was a greater probability of *Quercus agrifolia* with larger stem diameters developing sudden oak death. It also showed that beetle infestation of *Quercus agrifolia* was positively correlated with large diameter bleeding (McPherson et al. 2005). In a study conducted by Brown and Allen-Diaz (2005) current infection and senesce rates of stems and limbs ranged from 4 to 55 percent for *Q. agrifolia* basal area. The estimated future infection rates and senesce of *Q. agrifolia* basal area ranged from 15 to 69%.

Many researchers have stated that oak species in California, in particular Northern California, has not undergone adequate regeneration to replace aging trees since the early 1900s (Plumb and De Lasaux 1997). However, other experts in the field suggest that the regeneration of these oaks goes through waves or cycles. When the older generations start to die off then regenerations rates will start to blossom and there will be no need for replanting projects (Plumb and Lasaux 1997).

Although coast live oaks must overcome a number of obstacles in order to regenerate, researchers have identified conditions that can promote regrowth. For example, heavy rainfall especially during the first year of growth, can promote coast live oak regeneration. Managers may consider irrigating new oaks in their first year of growth if rainfall is low. The use of window or tree shelters, which help protect oaks from herbivores and some insects (Tyler et al. 2002), is another method managers can use to promote regeneration. Adams et al. (1992) used screen protectors and found that the screens significantly helped deter animals that damage oaks. The shade that was produced by the screen helped with growth because it reduced transpiration much like larger trees do for saplings. Reducing cover on non-native grasses can also promote regeneration. Tyler et al. (2002) showed higher mortality rates among oaks on ungrazed versus grazed land, potentially because ungrazed grasslands are dominated by non-native grasses that compete for water with the oaks. Also, the grasses may attract higher densities of insect herbivores, such as grasshoppers, that graze the oaks. Weed control can help lower the damage by animals that are attracted to thick herbaceous cover (Tyler et al. 2002). Adams et al. (1992) also found that controlling weed and other plant cover helped promote survival and growth of oaks whether it was done by artificial means or naturally.

ARASTRADERO PRESERVE HISTORY

Early History to Pre-1970

The Arastradero Preserve is located in Santa Clara County, at the foot of the Santa Cruz mountain range off Page Mill Road and Route 280. It is an open space park owned by the city of Palo Alto and managed by Acterra, a non-profit stewardship organization. Much of the information for this section was obtained from Lubin, et al. (2006) who have drafted a history of the Preserve.

The Ohlone Indians, known for their elaborate basket making skills, subsisted as hunters and gathers and inhabited present-day Palo Alto and the surrounding foothills before the Europeans arrived. According to historical accounts, the Ohlone used fire to manage the environment, which may have helped create an open woodland, versus dense forest, in many areas. The region’s population numbered about 400 people. Early land maps and historical information conclude that, after the Ohlone and prior to development in and around the City of

Palo Alto, the land was logged and used for farming and horse-ranching. The presence of rancheros and homesteads can explain the large number of invasive species still present today.

One of the earliest owners of this land was Maximo Martinez, born in 1791 at El Presido San Francisco. As compensation for his 25 years of service in the Spanish and Mexican armies, he was granted the Rancho del Corte de Madera by the Spanish government. In 1833, following the conclusion of the Spanish-American War, he began selling off portions of his land, but kept the best portions of land for his family estate. Martinez's adobe was used as a part of the family residence up until 1901 when it was sold (Wilson 1985). The Martinez estate was eventually purchased by Anson Parsons Hotaling, one of California's most well known whiskey distillers and distributers. Anson Parsons and his company were the western agents in charge of distribution and distilling for J.H. Cutter Whiskey in 1862 (Figure 10)(Heinemann 2005).

Figure 10: Drawing of an original J.H. Cutter Whiskey bottle

Another interesting use of the area occurred in 1917 when the United States War Department leased a total of 22,000 acres of land in the Menlo Park region for what was known as Camp Fremont (Figure 11). Camp Fremont was a World War I training facility, which included live artillery training. As late as 1990, shell casings, both live and non-viable, were found on the Arastradero Preserve.

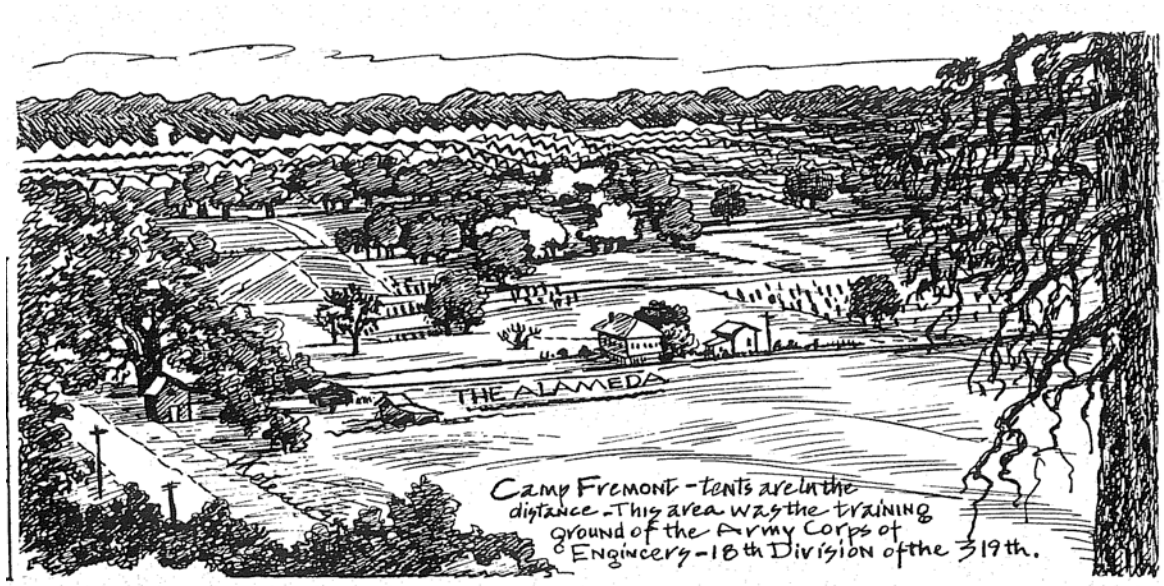

Figure 11: Depiction of Camp Fremont is during its operation**.**

In 1955, the City of Palo Alto hired Mr. Harley Bothwell and his wife Virginia as care takers of the area that became the Arastradero Preserve. The property, at this time, was primarily used for horse boarding and had three structures: a 5900 sq/ft home, a barn where the horses were kept, and a two bedroom house where the Bothwells lived. According to Annette Coleman Producer, a science/naturalist for the Baylands Nature Center in Palo Alto, Mr. Bothwell's responsibilities included cleaning the barn and collecting pasture fees from customers who boarded their horses on the property. During this phase of the property's history, the area was open only to those individuals boarding and riding horses. It is rumored that during this period the property had more horses residing on the property than Palo Alto was receiving for monthly pasture fees (Annette Coleman. Personal interview. March 22, 2008).

The Arastradero Preserve has had several owners and uses in recent history. In 1963, the Marthens owned a large portion of the present day Preserve and were horse and cattle ranchers. The Bressler family owned a portion of the Preserve, which was used for horses until a fire in 1985 that destroyed their home and ranch structures. In 1975, the City of Palo Alto purchased approximately 510 acres from Arastra LTD, a development company, which enlarged the preserve to about 622 acres. The Arastradero Preserve was officially dedicated as parkland for the City of Palo Alto in 1985.

History from 1970 to 1990

The history of Arastradero Preserve has been controversial since its creation in 1980 when the City of Palo Alto decided to dedicate a large amount of land for the creation of an open space park in the Santa Cruz Mountains. While this seemed to be a simple and positive action, the land was embroiled in controversy. In late 1969, the owner, Arastra LTD, proposed to develop the area into 1770 residential units. The City of Palo Alto quickly hired a team of expert consultants to examine the land use of this area and future potential development of these foothills. Seeing the value of this land for open space, the City of Palo Alto decided to update their City Comprehensive Plan and changed the land use designation in 1972 from 1 house per acre to 1 house per 10 acres.

Arastra LTD sued to the City of Palo Alto for what amounted to an improper “taking” of Arastra property. The United States District Court ruled in favor of Arastra LTD and the City eventually paid Arastra LTD a sum of $7,000,000 in 1976. With this payment the City of Palo Alto became the owners of the property. At that time, the property included a six-bedroom house)which remained from its previous owner, John Marthen), a large barn, and a smaller house with two bedrooms (Bay Area Action-Arastradero Preserve Project 1995). In 1982, the Palo Alto City Council dedicated roughly 432 acres of land towards the creation of Arastradero Preserve. Later in 1992, an additional 77 acres were added to the property. Neighboring this preserve is the Hewlett-Mullen property encompassing 100 acres; while this is not officially part of the preserve, it is included in the overall management plan for Arastradero Preserve (Figure 12).

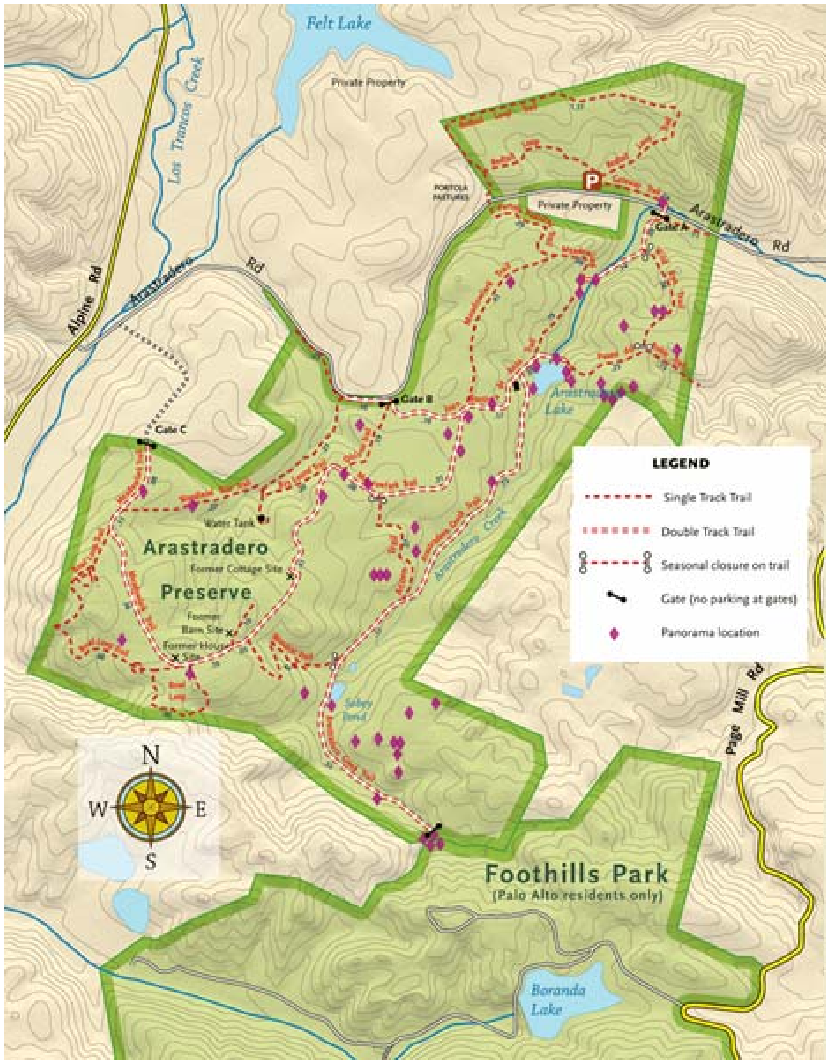

Figure 12: Boundary and Trail Map of Arastradero Preserve

From 1976 to 1984, the property contained a stable for about 20 horses and a 4,575 square-foot home which had been rented to various families (Duenwald 1984). In July of 1984, Mayor Betsy Bechtel appointed a citizens' committee to determine how the 500-acre parcel of land could be used as a park (Duenwald 1984). The committee decided to allow the park to be open to everyone, not just the residents of Palo Alto. Committee members also concluded that the park should remain unaltered and used primarily by hikers, bicyclists, and horseback riders. The horses that grazed on the property were placed in paddocks. Additionally, all utility wires that extended across the land were placed underground (Duenwald 1984). In 1984, the Preserve's open space mission and framework for the trails management plan was established.

Mayor Alan Henderson has thanked Hewlett Packard co-founder William R. Hewlett for donating to the city a tract of open space in the foothills in the 1980s. The land is located beneath Vista Point at Foothills Park and will give the city a “land-bridge” between the park and the city-owned Arastra Property. The land was donated as part of a recent subdivision package which allowed Hewlett to build 10 homes on 129 acres of foothill property. For nearly ten years, the people of Palo Alto debated on whether or not to incorporate the 77-acre plot of land adjacent to the Arastradero Preserve into the Preserve. Proposals for land use of the plot included selling the land, development and/ or incorporating it into the parkland. Proponents of adding the 77 acres of land to the Preserve were residents living next to the Preserve and members of the city council and Palo Alto citizens interested in preserving Palo Alto’s open space, opponents of incorporating the 77-acre plot as parkland argued that the land itself has limited value as open space and furthermore it would dramatically limit the city’s flexibility (Simitian 1992). Opponents suggested that the land could be worth as much as $20 million dollars and the money gained from selling it could be used to pay off city debt (Simitian 1992). City members who want the land to be incorporated into the Arastradero Preserve argued that it provides a safe environment for wildlife protects the beauty of the land and limits urban development. Ultimately, the proponents won.

<u>History 1990 to present</u>

Conservation and restoration of the Pearson-Arastradero Preserve officially began with Bay Area Action (BAA), a local non-profit group established in 1990. Bay Area Action negotiated a five-year contract with the city of Palo Alto in 1997 to provide stewardship services contributing to the repair and preservation of the foothills (Lubin et al. 2006). In 2000 the merger of Bay Area Action and the Peninsula Conservation Center formed Acterra (Action for a Sustainable Earth). In an agreement with the City of Palo Alto, Acterra acts as stewards of the preserve through the Arastradero Preserve Stewardship Project (Lubin et al. 2006). The main objective of the Arastradero Preserve Stewardship Project is to “respect, repair and restore the natural values of the Preserve (Lubin et al 2006).” Help from volunteers and staff keeps costs for maintaining the park low. The agreement between the city of Palo Alto and Acterra states Acterra will provide these steward services:

- “Coordinate all its activities on the Preserve with the City Manager, or designee

- Under the direction of the City, perform habitat restoration, removal and control of non-native, invasive weeds; trail maintenance and repair; litter removal; erosion control activities in accordance with the Arastradero Preserve Management Plan
- Under the direction of the City, provide and staff educational programs to educate the public about the Preserve and its amenities
- Under the direction of the City, conduct ecological research in order to monitor the resources and the impacts of visitor use on the Preserve
- Under the direction of the City, mobilize volunteers for Preserve projects and programs
- Under the direction of the City, organize fundraising for Preserve projects and programs
- Steward will provide the City with a proposed annual work plan to be approved prior to each fiscal year
- Steward may perform other services related to the preservation, protection and enhancement of the Preserve, as approved in writing by the City (Lubin et al 2006)."

After a stable partnership with the City of Palo Alto was developed, restoration began. Volunteers and staff began removing a house, barn, and cottage in February 1997 and completed the work in June, 1997 (Lubin et al. 2006). In order to minimize costs and encourage environmentally-safe practices, "over ninety percent of the wood from the barn and the entire roof of the main house were salvaged and re-used (Lubin et al. 2006)." Amphion Environmental compiled a list of soil types within the Preserve. They include Azule loams, Los Gatos gravelly loam, Los Osos clay loam, Pacheco clay loam and Pleasanton loam (Amphion Environmental Inc. et al. 1984). "These soils are well drained, slightly acidic and are typically used for range, recreation, and watershed activities (Amphion Environmental Inc. et al. 1984)."

Beginning in July, 1997 and continuing throughout the following year, volunteers clocked approximately 2,450 hours planting native species, building 800 feet of new trail, and removing invasive species and debris (Lubin et al. 2006). Between 1997 and 1998 the main objective of Acterra was to develop a restoration plan and identify areas in need of weed control and planting. Another focus was restoring native vegetation to the areas where the three former structures once stood. Discussion also took place for developing a mapping system to accurately determine the location of trails and vegetation. Acterra developed curricula for educational programs to ensure community involvement and awareness.

Between 1998 and 1999, the staff officially created a restoration plan focusing on "restoring the three former structure sites and Arastradero Creek,

- By planting oaks throughout the Preserve and removing weeds (Lubin et al. 2006)."
- Implementing mowing and solarization (heating soil using plastic) to remove invasive weeds. Cutting down seventy eucalyptus trees and weeds such as broom, fennel, milk thistle, purple star thistle, teasel, yellow star thistle and Italian thistle (Lubin et al. 2006).
- Conducting the first San Francisco Peninsula-South Bay Restoration Workshop at the Preserve in order to promote community involvement.
- Mapping specific features of the Preserve such as trails, roads and boundaries with GPS and incorporated into a GIS (Lubin et al. 2006).
- Many small oaks were planted and tagged/coded. Student groups began visiting the Preserve and an Education Coordinator was hired (Lubin et al. 2006).
- The Santa Clara Valley Chapter of the Audubon Society installed bird boxes in various locations throughout the Preserve (Lubin et al. 2006). The bird boxes were used to evaluate and tabulate the bird populations at the Preserve. Bullfrogs were also counted to see how many were living near the ponds.

Planting native grasses and vegetation occurred in 1999 and 2000. During this time, restoration work continued along the lower portion of Arastradero Creek, which was damaged in the fire of 1985. Projects along the creek included stabilizing the creek bank, installing an erosion control blanket, and planting willow (Lubin et al. 2006). Other vegetation planted along the creek included oaks, black walnuts, native grasses, buckeyes, and native shrubs (Lubin et al. 2006). Monitoring of oaks planted earlier in the year continued but unfortunately many of the oaks planted in the fall of 1998 along the trail did not survive. In order to suppress the regrowth of eucalyptus, Acterra personnel sprayed Rodeo, a well-known herbicide, on re-sprouts of trees taken out the previous year (Lubin et al. 2006). Staff observed a dramatic increase in ripgut brome between 1999 and 2000. Italian thistle and bull thistle continued to be invasive and volunteers removed these by hand. Volunteers also removed poison hemlock and replanted cleared areas with native species such as valley oak, coast live oak, toyon, snowberry, current, coffeeberry, mugwort and bee plant (Lubin et al. 2006). A program for monitoring European grasses was established at this time. Staff mowed about 40 acres of land in order to control non-native species (Lubin et al. 2006). With the help of experts, volunteers and staff placed raptor nest boxes and 18 quail covers throughout the Preserve (Lubin et al. 2006). In March of 2000, staff began gathering data on the GPS locations of bird, reptile, amphibian, fish, and mammal species (Lubin et al. 2006). Staff and volunteers continued to improve trails throughout the Preserve and map new ones. The following table gives an overview of the restoration activities and not a total of the restoration performed by Acterra at Arastradero from 2000-2004.

Table 1: Arastradero Preserve Restoration Activities.

Date	Activity	Purpose	Results
2000-01	Restoration lower Arastradero Creek 1.watered every 3-4 weeks 2.weed every 6 weeks	Increase survival rate of Oaks Supplement moisture during summer months	Increased new oak seedlings survival rate approx 70%
2000-01	Planted native grass seeds Restoration @ former barn and house location	Restoration Remove non-native species	Thriving native vegetation @ barn site invasion non-native Italian thistle @ house site
2000-01	Removed some eucalyptus trees and Scottish Broom Drained Sobey Pond Solarization-covering area with black plastic sheeting	Fire danger and non-native species Decrease bullfrog population To kill non-native species	
2002-03	Restoration	Remove non-native, i.e., poison hemlock, milt thistle	
2002-2003	Planting Planted 3000 sq/ft of creek area with native grasses	82 tress & shrubs by streambed Increased native-grass near creek with watering & mulching	Planted oaks, coffee berry, buckeye & snowberry Increased native grasses & survival rate of seedlings
2002-03	Inventory of plant seedlings	Restoration	30 coast live oaks @ former barn site ranging from 3.5-4.5 ft tall 9 of the 16 seedlings growing @ former house site
2002-03	Installed gopher cages & deer exclusion cages	To increase survival rate of planted acorns	Oak survival rate decreased by 37% (Lubin et al., 2006)

2003-04	Planting	32 Buckeye trees, 38 Oak trees, 130 shrubs & forbs, and 3200 native grass species	
2003-04	Inventory	Restoration	15% increase in *Nasella pulchra*, bunch grasses 31 Oak trees @ former barn site in good health and @ the former house site 16 Oaks from 1-9ft tall are growing appearing in good health
2003-04	Non-native inventory	Harding grass continues invading the former barn site 75 small eucalypti re-sprouted	Short of staff----------- Cut and treated with roundup (Lubin et al., 2006)
2003-04	Removed 49,000 non-native invasive species from the creek site and the parking lot	Restoration	Removed 69,000 invasive species throughout the Preserve (Lubin et al. 2006)
2003-04	Plantings	Planted over 3000 grass plugs and surrounded the plugs with rice straw	To increase survival of grass planting
2003-04	Install gopher cages and tree tubes	Protect seedlings	70% of 38 oaks planted near the creek are alive
2003-04	The sixth year of mowing	To cut non-native grasses	A increase of Italian rye observed with a decrease in Italian Thistle, Ripgut Brome, Yellow Star Thistle, Milk Thistle, & Soft Brome (Lubin et al., 2006)

The goals for the Preserve have evolved over time and now include the following:

- "Implement natural resource improvements that result in enhancement of wildlife habitat, increase in native plant populations, reductions in invasive plant population, and improved creek bank conditions

- Develop and deliver educational programs and interpretive materials to public audiences that increase awareness of natural resource, ecological and restoration issues on the Preserve
- Increase knowledge of the ecology of the Preserve and of restoration practices through information-sharing and ecological research efforts resulting in accurate and informative reports (Lubin et al. 2006)."

From 2005-2006, staff and volunteers planted over 60,000 native plants throughout the Preserve (Lubin et al. 2006), removed approximately 29,491 invasive plants, and created GIS maps of Preserve habitats, trails, and other key features. Staff added a Native Plant Nursery to the Stewardship Program in 2005.

A major event in 2007 was the completion of the Gateway Facility, a 1,177 square-foot green building to provide a visitor's center, space for the manager's activites, and space for organizing and training volunteers. The construction of the building "demonstrates best building practices of passive solar heating, solar electrical panels, hay bale wall construction, and use of recycled and reused building material (Arastradero Gateway Stewardship Facility Brochure 2006)."

Also, in 2007, to the Preserve managers evaluated and monitored the approximately 277 oaks on the Preserve and worked to organize data collected previously into standardized spreadsheets. The Preserve staff wanted to know whether or not management practices conducted over the years were harming or contributing to the survival of the planted trees.

STUDY SETTING and SAMPLING DESIGN

The Arastradero Preserve managers have worked hard at habitat restoration, especially planting oaks. Although oak woodlands are native, they are somewhat sparsely distributed at the Preserve and managers have wanted to expand the distribution and density of oaks. However, managers did not know whether oaks were naturally regrowing at a rate that could make oak restoration restoration unnecessary. Moreover, information on natural regeneration could provide information on which oak species may need management help, where planting might best be done, and what conditions might promote successful regeneration. Given this background, this study of natural oak regeneration at Arastradero Preserve in Palo Alto used field data analyzed with geographic information systems (GIS) and statistical analyses to assess these questions:

1) Are valley oak, blue oak, and coast live oak regenerating naturally at Arastradero and, if so, what are the characteristics of the saplings?
2) Is there a relationship between saplings and a number of different local factors including the amount of canopy cover, amounts of different ground covers, numbers of gopher holes, and proximity of trees and shrubs?
3) Is an oak planting program needed at the Preserve and, if so, how and where should the oaks be planted to best ensure their survival?
4) What are our overall recommendations for future oak restoration at the Preserve?

Setting

The Arastradero Preserve is located in northern Santa Clara County on the San Francisco Bay peninsula, approximately 40 miles south of San Francisco. The area experiences a Mediterranean climate characterized by wet winters and dry summers. Temperatures range from an average high of 78^{o}F in July to an average low of 39^{o}F in January. Rainfall averages approximately 16 inches in Palo Alto, with the precipitation occurring primarily between October and April. This Santa Cruz mountain foothill region has gently rolling hills from 200 to 800 feet in elevation.

Oak woodlands are a dominant natural community at the Preserve, with coast live, blue, valley and some black oaks found on site. In addition to the oak woodlands, the Preserve supports a number of other natural communities indicative of northern California's Mediterranean climate, diverse soil types, and topography.

Grasslands are a prevalent community on the Preserve and are dominated by non-native annual grass and forb species. The native, perennial bunch grasses that evolved in the region are now only a small fraction of the grassland community. Unlike the non-native invaders, native grasses stabilize soil and improve soil quality wherever they are found. They increase water infiltration and fertility and also recycle nutrients. Their deep and fibrous roots (up to 12 feet in length) can tap deep soil water, allowing them to stay green year-round. Because of this, California native grasses are relatively inflammable and can provide low-maintenance fire buffers around residences. Oaks now live amid a sea of non-native grass species, which may be hindering oak regeneration (Bernhardt and Swiecki 2001).

Another common plant community is the riparian zone, the swath of habitat adjacent to a river or stream, the area between the uplands and the river. A healthy riparian zone provides vital habitat for a wide variety of fish, birds, and other wildlife. These areas are often the sole available habitat for amphibians and invertebrates that need moist conditions. Although riparian zones may occupy a relatively narrow band of territory, they are critical to maintaining the biodiversity of the more extensive, adjoining uplands. Some riparian corridor still remains on site, but most has been reduced or completely removed in some segments of the Preserve. Valley oaks, in particular, benefit from a healthy riparian zone as they are often part of the stream-side forest.

Stand Selection

Oak woodland stands were sampled throughout the Preserve to assess regeneration activity. The sampling design for this study was modeled after the research by Swiecki et al. (1993) who studied blue oak regeneration at 15 locations in California. We modified their methods for our study in a number of ways including:

1. Studying only one site.
2. Collecting data on three oak species.
3. Reducing the number of parameters for data collection.

We selected 12 oak stands for study within Arastradero using a tree species distribution map created by Robert Frazer (2004) (Figure 13) and we sampled in 10 of them. Five criteria were used to select stands for surveying:

(1) canopy coverage had to be equal to or larger than one acre,

(2) the target tree species had to be the highest frequency species in the stand,

(3) grassland had to be adjacent to the stand,

(4) areas with juvenile oaks previously planted by volunteers were not sampled, and

(5) mowed areas were not sampled.

Cyrus Haitt, GIS technician with Arastradero, provided data to develop maps of the oak plantings (Figure 14) and the regions of the Preserve that were mowed (Figure 15). Four different oaks stands were located for each of the three oak species being studied. Occasionally, contiguous stands were combined for sampling. For example, neither valley oak stand number 6 nor 6VO, adjacent to it, met the one acre coverage criteria. So, these two areas were combined together and sampled as one stand.

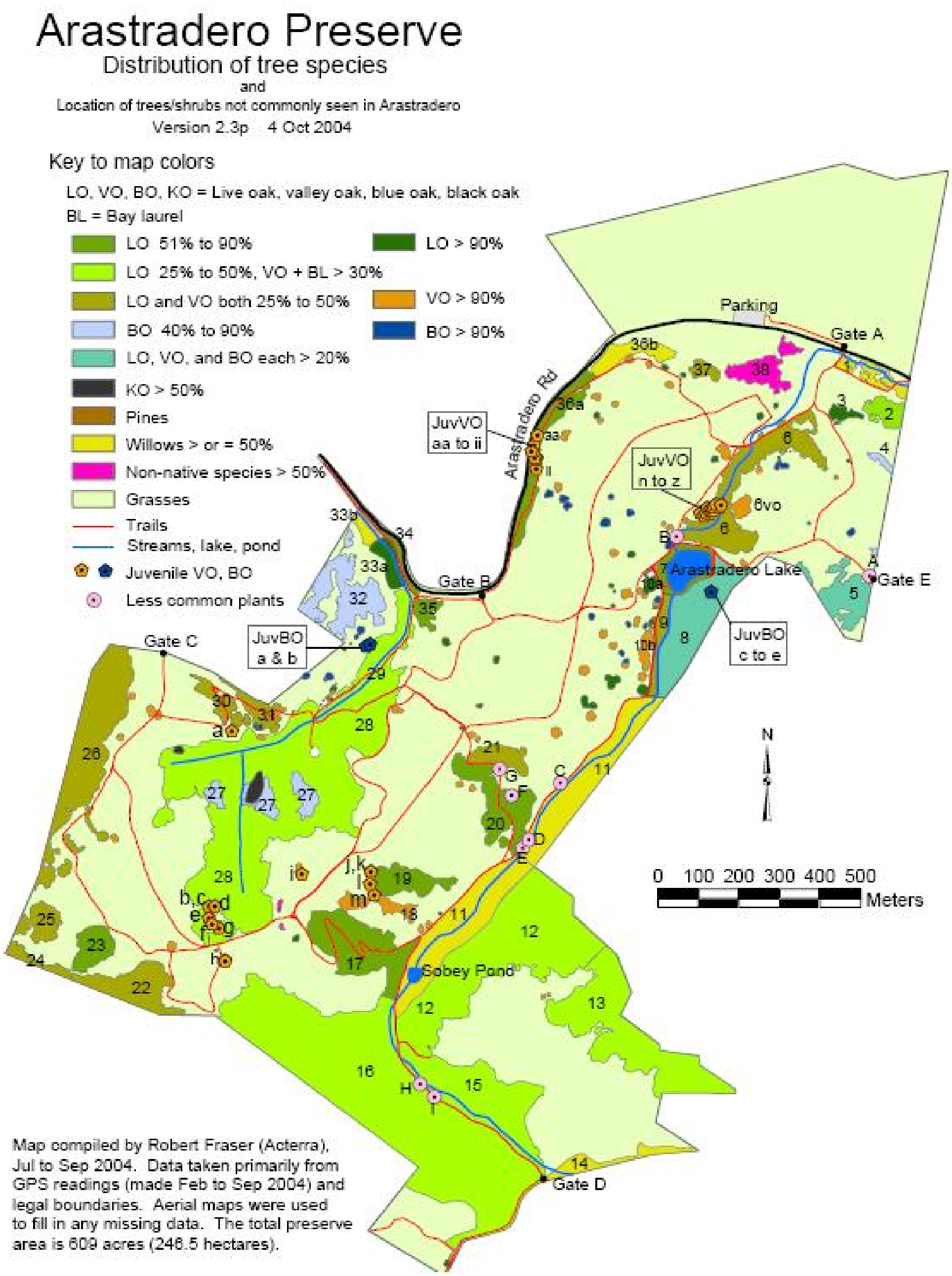

Figure 13: Distribution of Tree Species at Arastradero Preserve (R. Fraser, 2004).

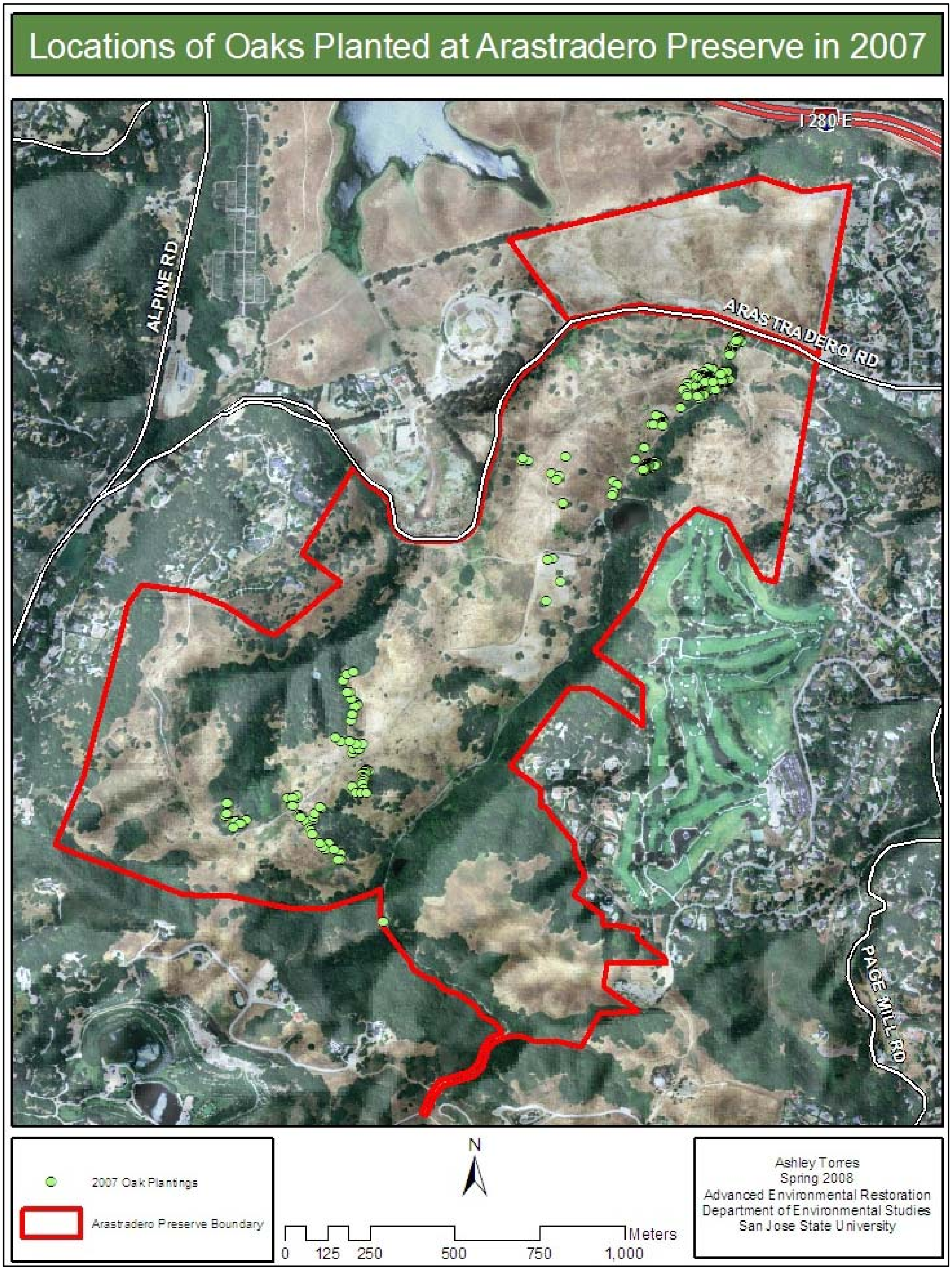

Figure 14: Locations of Juvenile Oaks Planted at Arastradero Preserve in 2007

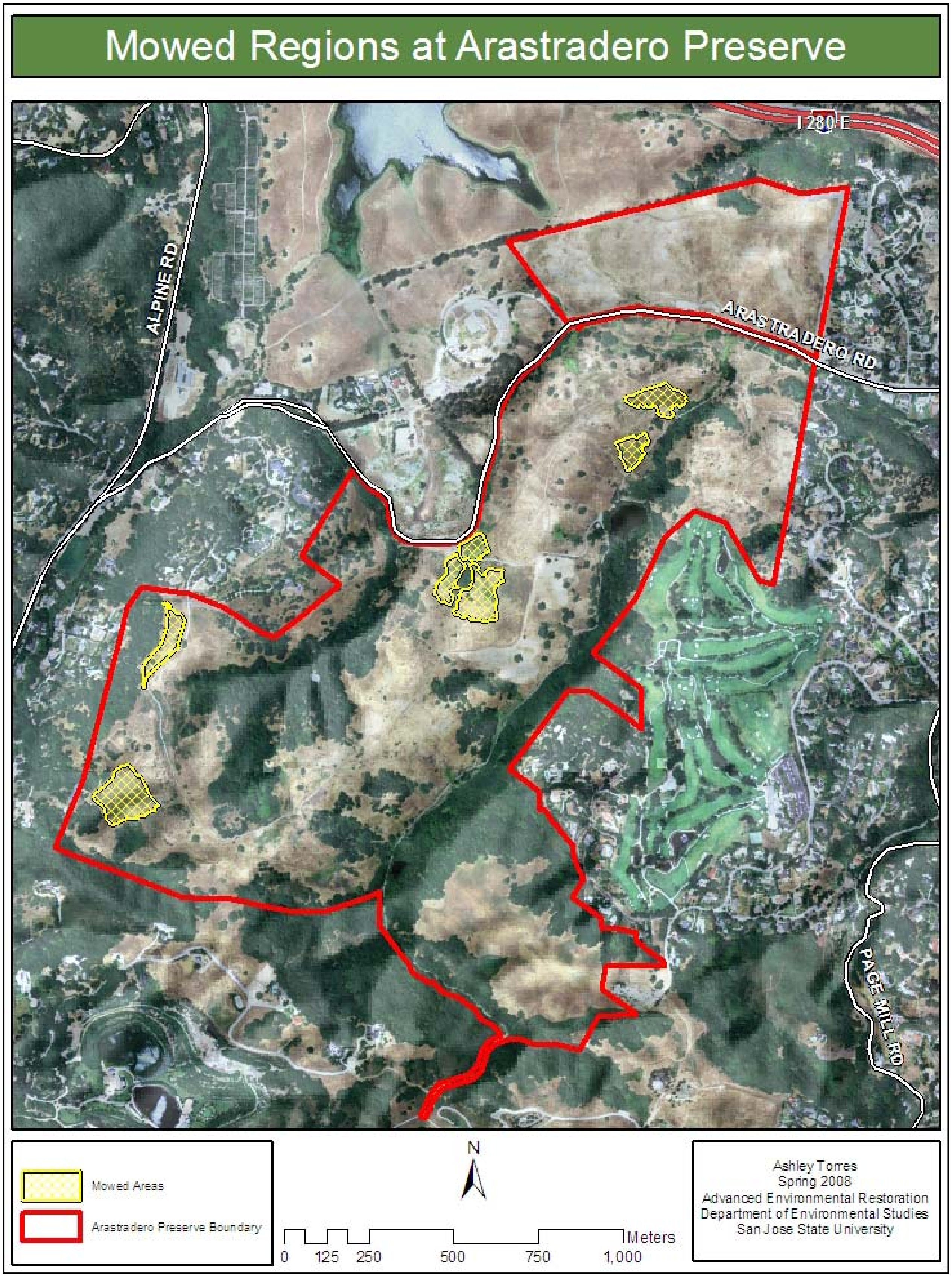

Figure 15: Locations of Mowed Regions at Arastradero Preserve

Sampling Design

Aerial imagery of the area (1-meter resolution), the polygon shapefile of the Arastradero boundary, and the point shapefile indicating the location of previous plantings were obtained from Arastradero. Before any of the data files were imported into ArcMap, they were projected into the coordinate system NAD_1983_UTM_Zone_10N. The files were then added to a new ArcMap file to create a map of the 10 stands selected for sampling (Figure 16) using the aerial imagery and the tree distribution map. A 50m x 150m, grid made up of 75 10 x 10 meter plots, was drawn over each stand. We sampled in three strata: tree (within the tree canopy), adjacent (at the edge of the canopy), and grassland (outside the canopy) (Figure 17). Ten 10 x 10 meter plots were randomly selected for sampling within each of the three strata in each of the stands. UTM zone coordinates for the center of each plot were calculated and exported into a Microsoft Excel Worksheet that included the corresponding stand number, plot number, and strata.

DATA COLLECTION

During the initial phase of the study, students were assigned one species of oak to study, blue oak, valley oak, or coast live oak. The students became "experts" on their species by learning about the identification characteristics of the specific species throughout all stages of growth. For the field data collection, the class was divided into four groups of three to five people. Each group had an expert of each species in order to identify species in the field. The groups were then assigned three oak stands to survey. They were given a data sheet with UTM coordinates of the plot centers and a map of its location within the Preserve. The protocols for data collection (Appendix 1) and three different data sheets for field collection (Appendix 2) were also distributed to the class and a document outlining the protocols for field data collection. The data sheets received included sheets to record plot data, sapling data, and adult tree data. Groups were given the following supplies: GPS unit (Trimble GeoExplorer 3, Garmin Etrex, or Garmin Etrex legend HCx), 10 meter rope, 15 pin flags, 100 ft open reel transect tape, compass, clinometer, spherical densitometer, and soil corer.

After some training was provided to all students on how to use the equipment and to properly read and use the GPS units the groups began collecting data. Data collection ran from March 16, 2008 through April 20, 2008.

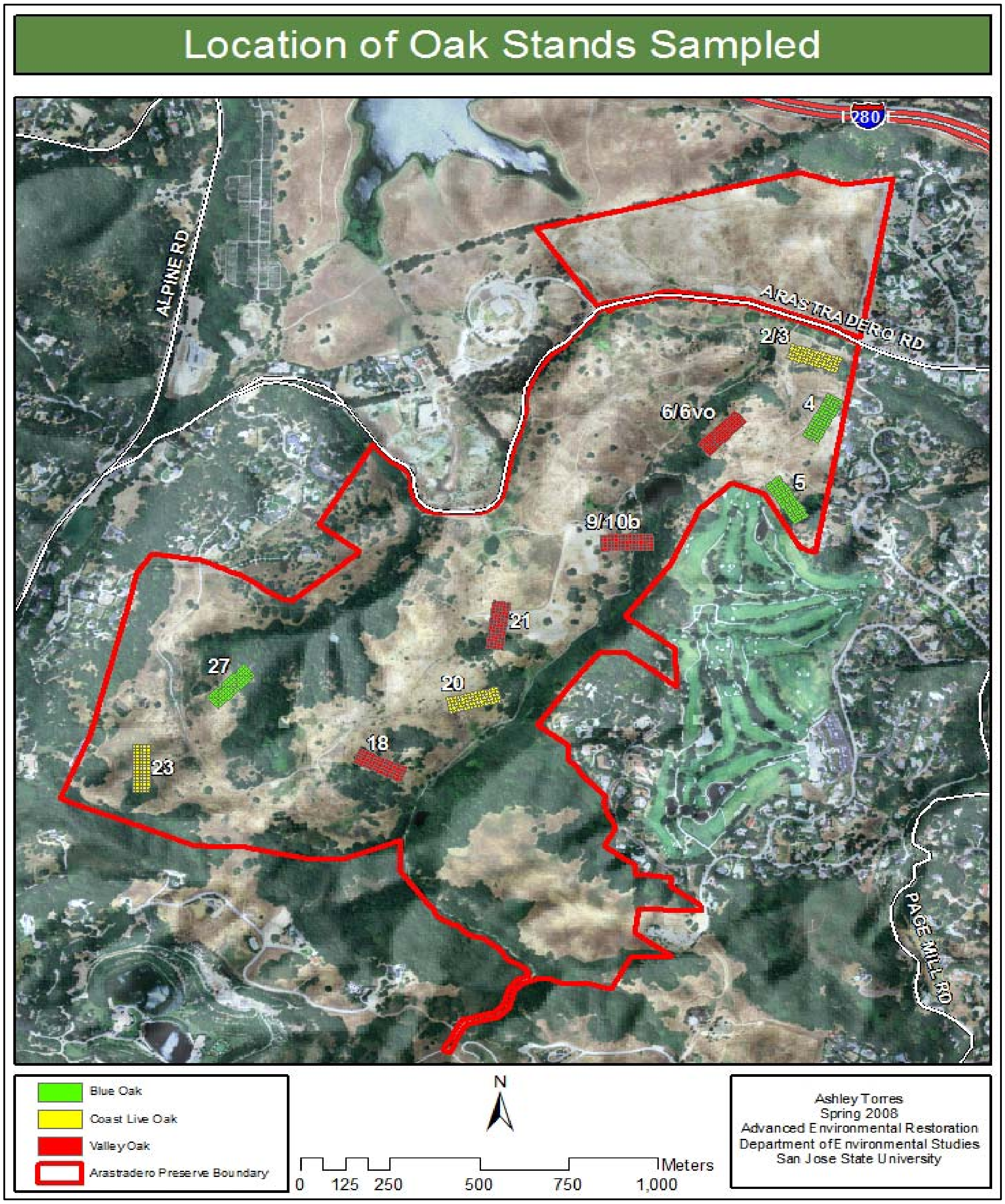

Figure 16: Location of Stands Sampled (with stand number).

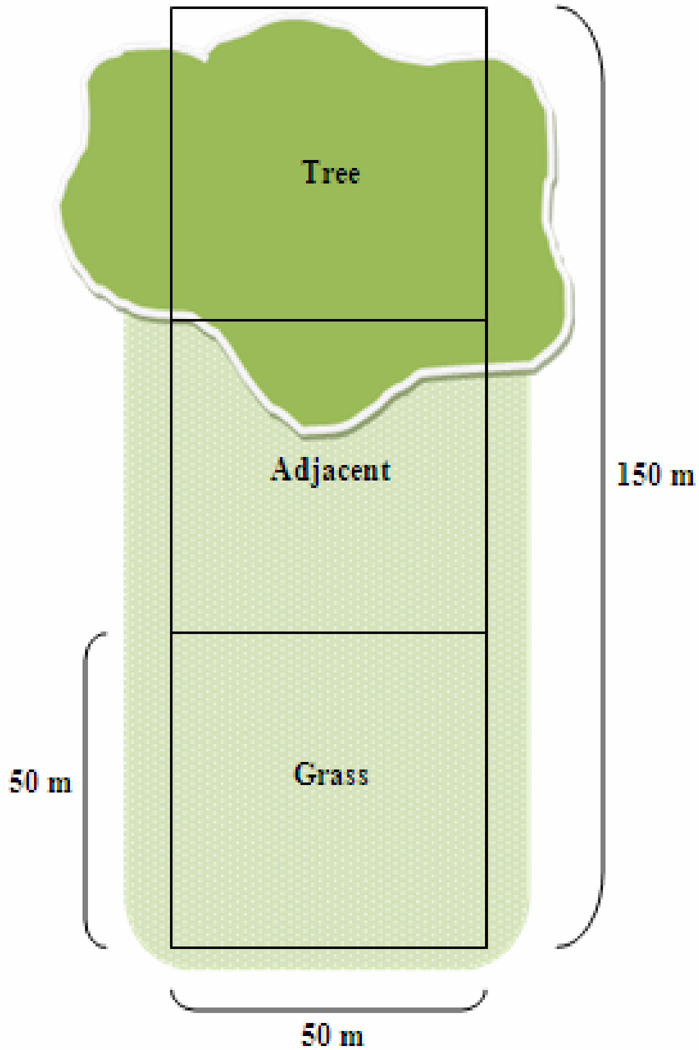

Figure 17: Stratified Classification used for Each Stand

<u>Plot Data</u>

Field teams located the center of the plot using a GPS unit, marked it with a tent stake, and recorded the actual GPS coordinates displayed on the unit. Groups using the Garmin units were also asked to record the margin of error that the unit displayed for each GPS location recorded. The 10-meter rope was then folded in half, one person stood at the center holding one end of the rope while another researcher walked around the center, making a circular plot that was specified using pin flags. This technique created a circular plot with a diameter of 10 meters (Figure 18).

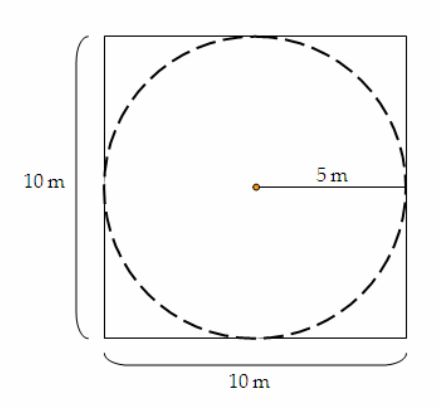

Figure 18: Sampling Plot Design

Multiple measurements were recorded on the data sheet for the plot as a whole. All measurements taken for the plot were collected from the center. Canopy cover was measured with a spherical densitometer (Figure 19) by having someone stand at the center of the plot and recording the number of squares that had tree canopy in them. If the trees covered 50% of the square then it was to be counted; however, if there was less than 50% tree coverage then the square was not counted. Four measurements were taken, one from each cardinal direction (north, south, east and west), using a compass as reference. The four readings were then added together resulting in the total percent cover of tree canopy for the entire plot.

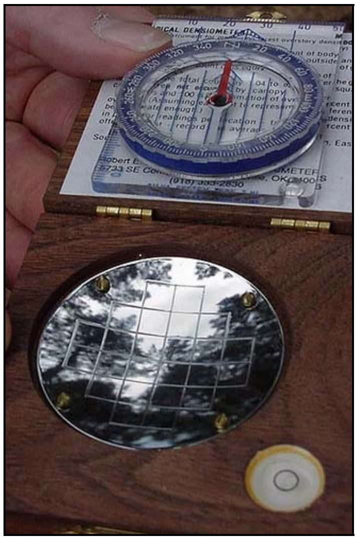

Figure 19: Spherical Densiometer

Slope was considered a categorical variable and researchers were asked to characterize the slope as being steep, moderate, slight or flat. Aspect was calculated by using a compass to determine the direction that the sun hits the plot. The compass was aligned to show magnetic north and the appropriate reading in degrees was recorded. Soil depth was measure by pushing the soil corer into the ground as far as it could go and measuring the length of the soil inside of the corer. Soil type was classified in the field from the core sample as rocky, organic, sandy, or high in mineral content. We counted the number of gopher holes within each plot and, finally, the number of saplings by species. During data collection, all juvenile oaks were considered "saplings", even if very small. If the species of the sapling was not known or undeterminable, we took a picture of the oak and bring it into class for additional identification assistance and the photo number was recorded on the data sheet next to the corresponding plot number. The number of tree and shrubs located within the plot was recorded along within the abundance and species. Finally, percent cover of shrubs, grasses, litter and bare soil were estimated for the entire plot.

Sapling Data

Data on individual saplings were collected for all juvenile oaks located in the plot. If we found >12 twelve saplings in a plot, three saplings were chosen and classified as small, medium and large, based on their height. We measured these three and then, recorded the number of other saplings in the plot of similar size. For each sapling chosen, we recorded the GPS location of the plot and the species, and we measured the basal diameter and height, distance to the canopy of the nearest shrub, distance to the trunk of the nearest tree of any species, and distance to the nearest tree of the same species. Canopy cover readings were taken from just above the tallest stem of the sapling. We also recorded signs of herbivory or girdling and the health of the sapling.

Adult Tree Data

We collected data on the adult oaks trees in the plots, including the GPS coordinates of the plot, the species of oak, height, diameter, the health of each tree (dead or alive), and any signs of distress. Height was measured using a clinometer (Figure 20) and the calculations shown in Figure 21. Diameter at Breast Height (DBH) was collected by measuring the circumference of the trunk in the field and dividing that number by 3.14. For oaks with multiple trunks, measurements were taken on up to three of the largest trunks and the total numbers of trunks were recorded.

Figure 20: Clinometer

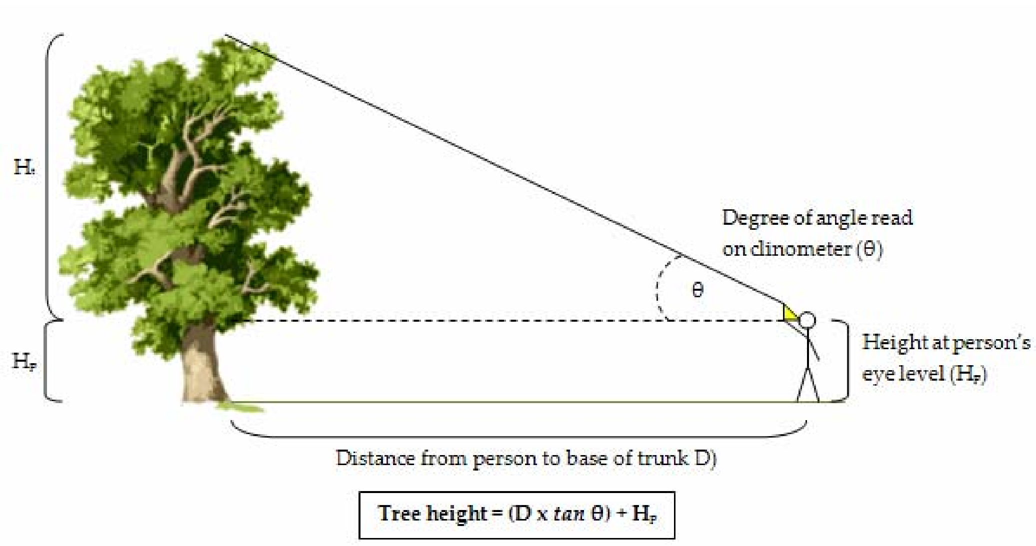

Figure 21: How to measure the height of a tree on a flat surface.

<u>Data Preparation</u>

After all data collection had been completed, the field data were compiled into a formatted data sheet in Microsoft Excel. Each group was given a list of directions on how to properly input their data in order to minimal data differentiation between groups (Appendix 3). The field data were then compiled into a master list that was distributed to the statistics team and the GIS team for analysis. Due to time limitations, only 10 of the 12 stands were surveyed and we collected data on only 166 of the 360 proposed plots.

DATA ANALYSIS

GIS Mapping

Field data were appended to the GIS files of the sampling plots. The appended data included the actual GPS coordinates recorded at the plot, as well as the number of blue, valley, and coast live oak saplings, aspect and slope. We altered the symbology for the layer to display the number of total saplings (all species) using a graduated color ramp and plots were labeled with their plot number. The total abundance of saplings per plot was divided into eight breaks (0, 1-5, 6-10, 11-15, 16-20, 21-25, 26-50, 51 or more) for display on the maps. We downloaded two 10-meter resolution digital elevation models (DEMs) from GeoCommunity to simulate the terrain throughout Arastradero Preserve and projected them into NAD_1983_UTM_Zone_10N. They were mosaiced before being imported into ArcMap. A major roads shapefile was accessed from ArcGIS 9 ESRI Data & Maps Media Kit DVD set and added into ArcMap to show the important roads surrounding the Preserve. We then produced maps based on the collected field information. Final maps included the locations of the stands and plots that were sampled over the entire Preserve and individual stand maps were created to show where plots were located and how many saplings were found and where (Appendix 4). Appendix 5 provides the actual UTM coordinates of the plots sampled. Once the individual stand maps were made, a small table was inset into each map showing the plot number and the number of blue, valley, and coast live oak sapling found in the corresponding plot.

Statistics

SYSTAT 12@ and MySTAT@ (SYSTAT Software, Inc., Richmond, CA) were used to determine how saplings were distributed and which environmental factors correlated with sapling data. When necessary, continuous variables were log transformed in order to meet expectations for normality. Percentages were converted into proportions and arcsine transformed. One variable, soil depth, was not analyzed due to data irregularities. We analyzed the factors potentially affecting the number of total saplings and saplings by species per plot. We tested whether the location and heights of the individual saplings were associated with specific factors. Finally, we compared small saplings (under 10 inches tall) to true saplings (>10 inches tall) (Swiecki and Bernhardt 2001) with respect to different factors.

We used descriptive statistics to characterize the saplings and used general linear models, GLMs, to determine which categorical variables (strata type, soil type, stand type, and slope) were significantly associated with sapling number per plot, individual sapling height and presence, and small versus true saplings. We used least squares linear regression to conduct analyses on plot data using continuous variables (number of gopher hole, canopy cover, grass cover, litter cover, bare ground cover, shrub cover, shrub number, and tree number). Data from individual saplings were analyzed using principle components analysis (PCA) to determine which factors most correlated with sapling presence. We varimax rotated data to minimize the number of factors with high component loadings and included component loadings of 0.60 and higher. Since many individual samplings were in the same plot, using data from all individual samplings in the PCA analysis resulted in pseudo-replication. However, this analysis, in conjunction with the others helped, provide a picture of factors associated with sapling number and location.

RESULTS

<u>Species Regeneration and Qualities of Saplings</u>

We sampled 10 stands, 3 dominated by coast live oaks, 3 by blue oaks, and 4 by valley oaks. Saplings were found in 71 of the 166 plots, or 43% of the plots we sampled. Of these 166 plots, 24% contained live oak saplings (43/166 plots), 5% contained blue oak (8/166), and 11% contained valley oaks (20/166) (Figure 22). Plots with coast live oaks were found equally in all three stand types. The 8 plots with blue oak seedlings were found only in blue and valley oak stands, while the 20 plots with valley oak seedlings occurred only in valley oak stands. Saplings of all three species were most likely to occur in the tree strata; in fact, 90% of the plots in the tree strata contained saplings (Figure 23). Of plots sampled in adjacent and grassland strata, 25% and 13%, respectively, contained saplings (Figures 24 and 25). In plots where live oaks occurred, the number of saplings per plot ranged from 1 to 40. Six of these plots had 20 or more saplings. Blue oak saplings per plot ranged from 1 to 14 plants. The range for valley oaks was 1 to 265 saplings per plot; the 4 most populous valley oak plots contained 55, 72, 76, and 265 saplings, respectively. Appendix 4 provides GIS maps with the locations of all plots sampled for each of the 10 stands sampled with data on sapling numbers by species for each plot.

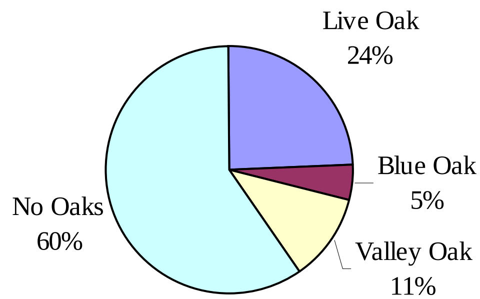

Figure 22: Percent of Plots with Saplings (strata combined; N=166)

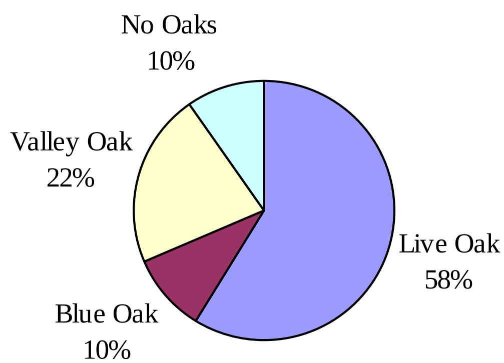

Figure 23: Percent of Plots with Saplings in Tree Strata (N=41)

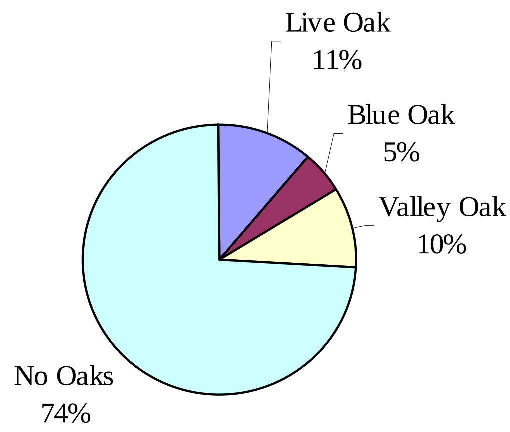

Figure 24: Percent of Plots with Saplings in Adjacent Strata (N=61)

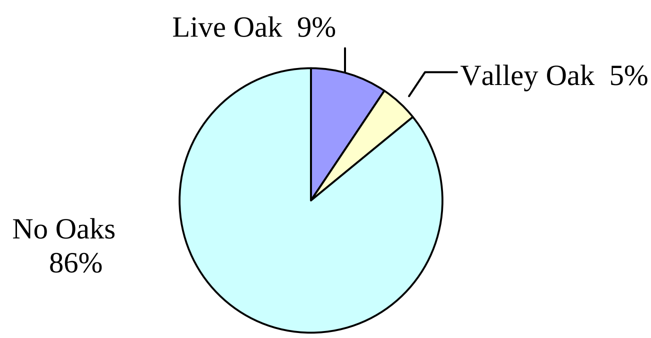

Figure 25: Percent of Plots with Saplings in Grass Strata (N=64)

Canopy cover in the tree strata averaged 44% (SE = 6.3), 11% (SE = 2.9) in the adjacent strata, and 2.5% (SE = 1.4) in the grasslands. The number of gopher holes per plot in the grassland strata averaged 12 per plot, similar to the adjacent strata, which averaged 10 gopher holes per plot. The tree strata, with 6 per plot, had much less gopher activity than the other two strata (Figure 26). Plots with live oak and valley oak saplings had much higher percentages of canopy, litter, and bare ground cover than plots without saplings; live oak plots also had much less grass cover (Figure 27a, b). The 8 blue oak plots did not provide enough data for graphing.

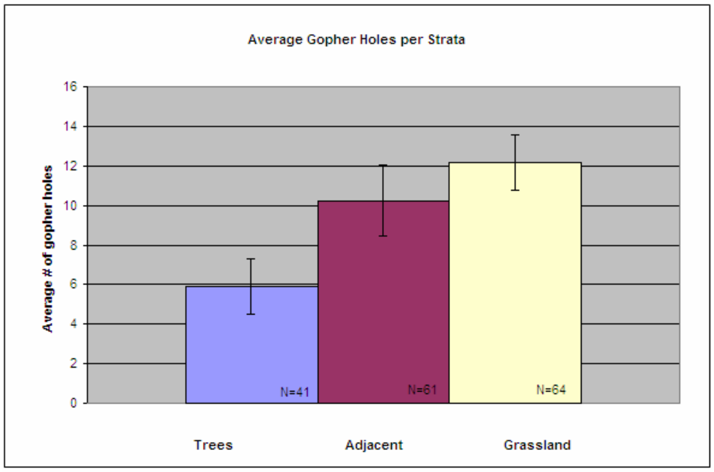

Figure 26: Number of Gophers Holes per Plot (mean ± SE)

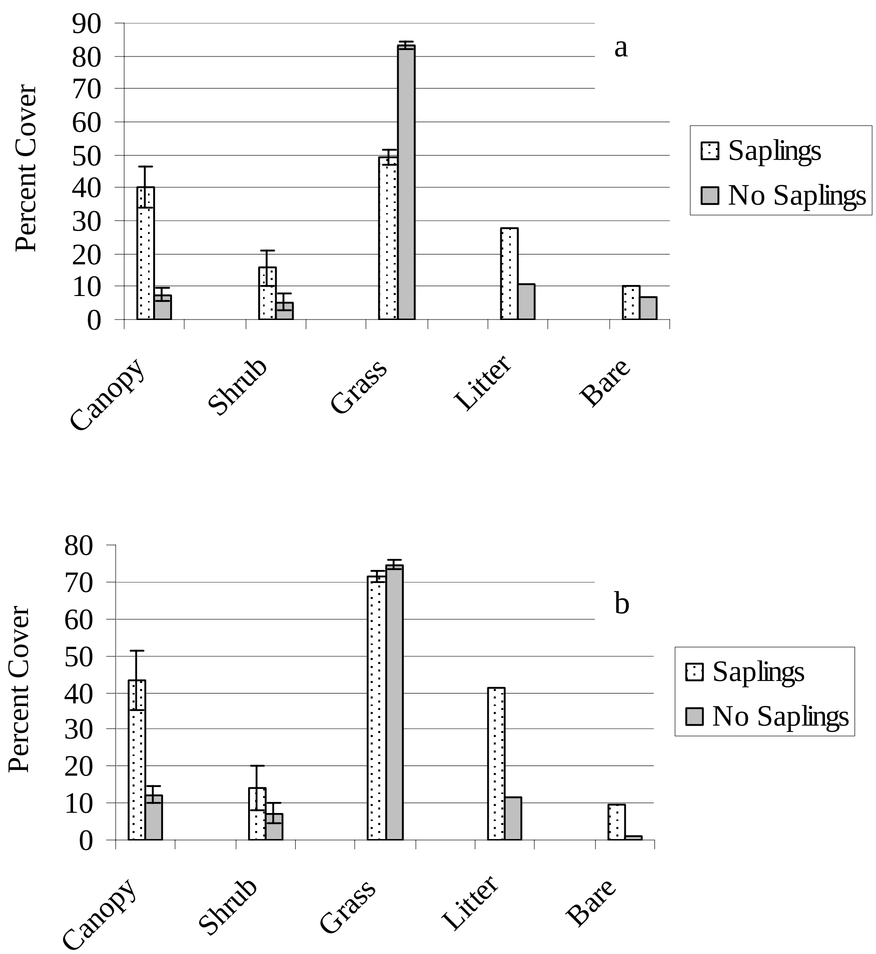

Figure 27: Percent Cover in Plots (mean ± SE) With and Without a) Live Oak Saplings and b) Valley Oak Saplings

We measured 189 individual young oaks and found that the great majority (n = 123) were small saplings or seedlings under 10 inches tall (Figure 28a). Of the 66 true saplings (>10 inches in height; Figure 28b), 58 were live oaks, 5 were blue oaks, and 3 were valley oaks. Only 6 plants were above browse height and all of these were live oaks. The tallest valley oak sapling measured 3 feet and the tallest blue oak measured only 1.2 feet tall. The average distance to a tree of the same species was the greatest for live oak saplings (average distance of 20 feet), and the shortest for blue oak saplings with an average distance of 15 feet (Figure 29). Valley oak saplings were an average of 16 feet away from a tree of the same species. The distance to the nearest shrub was similar for the three species, averaging 12 feet for coast live and valley oaks and 15 feet for blue oaks.

We measured 66 adult trees in our plots consisting of 34 live oaks, 8 blue oaks, 18 valley oaks, 5 California buckeyes, and 1 California bay. The blue and live oaks averaged 36 feet tall; valley oaks averaged 45 feet tall. All were alive and only one tree, a live oak, appeared to be in poor health.

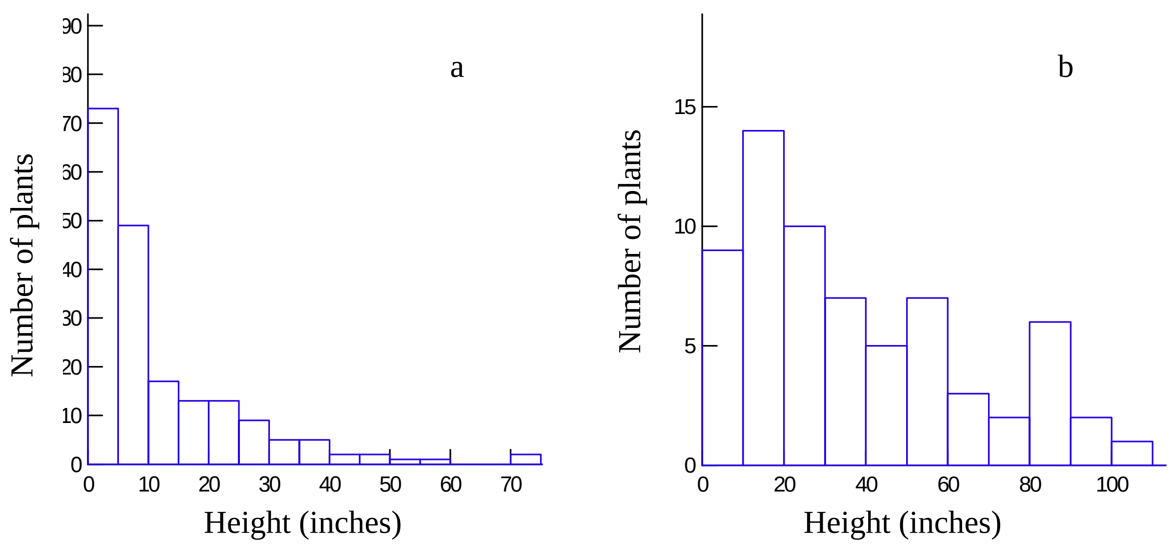

Figure 28. Histograms of (a) all sapling heights (N=189) and (b) true sapling heights (N=66).

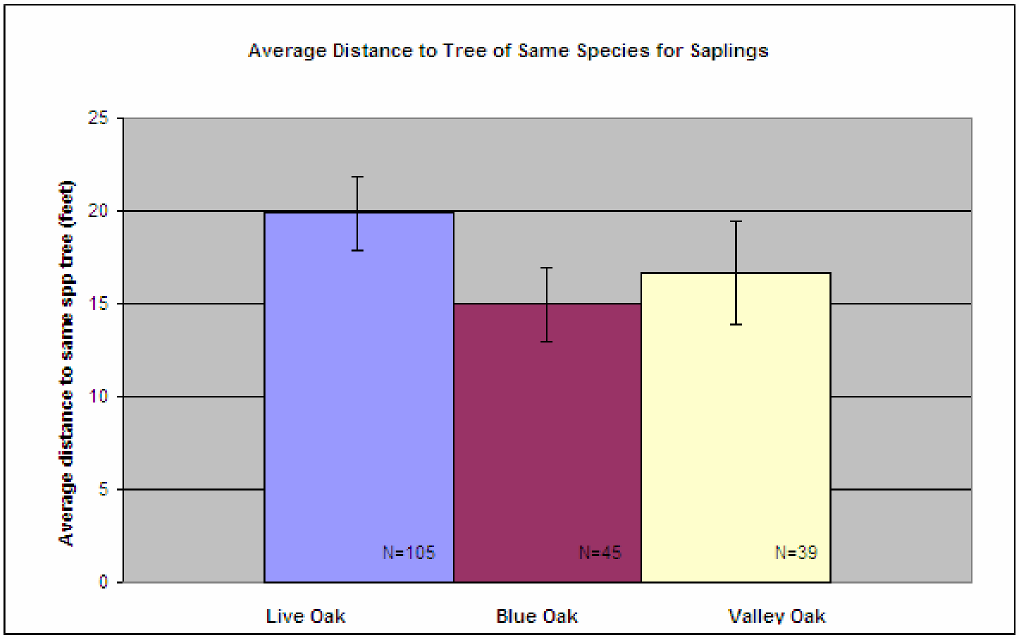

Figure 29: Distance (mean ± SE) of Individual Saplings to the Nearest Tree of the Same Species

Factors Associated with Sapling Location

While plots with coast live oaks occurred in all 3 stands and strata, live oak saplings were much more likely to be found in the tree strata of live oak stands ($F_{4, 166} = 10.336$; $P < 0.000$) than elsewhere. Blue oaks were also more likely to be found in the tree strata of blue oak stands ($F_{4,166} = 3.11$; $P = 0.017$) than elsewhere. Plots with valley oaks occurred only in valley oak stands and were much more likely to be found in the tree strata versus adjacent or grassland strata ($F_{2,166} = 4.686$, $P = 0.011$).

Regression analyses showed positive relationships between the number of live oak saplings per plot and canopy cover, number of shrubs, and number of trees per plot. The total number of saplings per plot showed a positive association with litter cover and canopy cover (Table 2). There was inadequate data to test relationships between plots with blue oaks and other factors, as blue oaks occurred in only 8 plots. Valley oaks occurred in 20 plots and these analyses would also benefit from more data.

Table 2. Regression Results for a Range of Factors and Saplings per Plot (N=166 for each test)

	Live Oak Saplings	**Valley Oak Saplings**	**All Oak Saplings**
Grass Cover	0.214	0.020	0.156
Litter Cover	0.166	0.021	**0.257**
Bare Cover	0.001	0.015	0.008
Canopy Cover	**0.296**	0.024	**0.300**
Shrub Cover	0.103	0	0.054
Gopher Holes	0.004	0.013	0.006
Aspect	0	0.003	0.003
Shrub Number	**0.343**	0.001	0.108
Tree Number	**0.340**	0.035	0.063

Significant results in bold

When analyzing factors associated with individual saplings, we found distance to a tree of any species, distance to shrubs, and canopy cover all correlated well with seedling location for all three oak species. Canopy cover and distance to tree of any species accounted for 51% of the variance in both blue and live oak sapling location. For valley oak saplings, distance to a tree of any species and distance to shrubs combined with canopy cover accounted for 48% of the variance in valley oak seedlings (Table 3).

Table 3. Component Loadings (PCA for Factor 1) and Percent of Variance Explained

	Live Oaks	**Blue Oaks**	**Valley Oaks**
Distance to a tree	0.927	0.826	0.857
Distance to tree of same species	0.916	0.754	0.876
Distance to shrub	0.107	-0.262	0.580
Percent canopy cover	-0.590	-0.840	-0.287
Variance Explained	51%	51%	48%

Small versus True Saplings

The location of small saplings (≤10 inches) and true saplings (>10 inches) differed with respect to a number of factors (Table 4). True saplings occurred in plots with many fewer gopher holes ($\bar{x}$ = 11.3, SE = 1) compared to plots with small saplings ($\bar{x}$ = 7.8, SE = 1.2) and the percent of bare ground in plots with true saplings ($\bar{x}$ = 17%, SE = 2.2) was nearly double that of plots with small saplings (8%, SE=1.6). True saplings were, on average, further from the nearest tree than small saplings ($\bar{x}$ = 14.8 feet, SE = 1.7 versus $\bar{x}$ = 10.6 feet, SE = 1.3).

Table 4. Comparison of Small versus True Saplings with Respect to a Number of Factors

	GLM Result
Gopher Holes/plot	**$F_{1,190}$ = 8.53, p = 0.004**
Distance to nearest shrub	$F_{1,190}$ = 0.002, p = 0.964
Distance to nearest tree	**$F_{1,190}$ = 7.825, p = 0.006**
Number of shrubs/plot	$F_{1,192}$ = 0.004, p = 0.947
Number of trees/plot	$F_{1,192}$ = 0.661, p = 0.417
Canopy cover over sapling	$F_{1,190}$ = 1.10, p = 0.451
Shrub cover in plot	$F_{1,192}$ = 0.571, p = 0.296
Grass cover in plot	$F_{1,192}$ = 1.515, p = 0.220
Litter cover in plot	$F_{1,192}$ = 0.043, p = 0.836
Bare ground cover in plot	**$F_{1,192}$ = 11.746, p = 0.001**

Significant results in bold.

DISCUSSION

Characteristics of Saplings

Our study shows that valley, blue and coast live oak acorns are germinating at Arastradero Preserve. Of the 166 plots sampled, over 40% contained young oaks, but the great majority of these plants were ≤10 inches tall and many were seedlings, i.e. growing directly from the acorn. Thus, many had germinated in the previous fall. For the most part, these 3 oak species are not achieving heights above the browse level. Only 6 saplings were over browse height of about 5 feet tall (Bernhardt and Swiecki 2001), and all of these were coast live oaks. Saplings growing above browse height are much more likely to be recruited into tree stage; this is because they are less likely to be killed by drought, fire, and large grazers (Bernhardt and Swiecki 2001). The likelihood of small saplings surviving until adulthood is low. Young oaks tend to have high mortality rates during their first two years; this mortality rate is especially high during the second year after depletion of all their acorns' nutrients (Pavlik et al. 1991). Ballard et al. (2002) note that seedlings cannot be used to determine regeneration success, because "seedlings are ephemeral in the oak woodland." Based on this information, it seems that very few if any valley and blue oak recruits are surviving to adult tree stage. Our findings are supported by other researchers who have found that oaks are having difficulty getting from the seedling or small sapling stage to above browse height, where they have a much greater chance of survival.

We did find that all the adult oak trees in our plots appeared relatively healthy. Thus, current mortality of adults, as assessed by this sample, is not outstripping recruitment (Tyler et al. 2006). However, our sample of adults was small; a much more complete study is needed to assess current and predicted rates of adult tree mortality and the level of recruitment needed to compensate for losses of adults. Threats such as Sudden Oak Death and climate change suggest that healthy rates of recruitment will be essential in the future.

The percent of plots containing coast live oaks, at 24%, greatly exceed blue oaks and valley oaks (4% and 11%, respectively). In their review, Tyler et al. (2006) point out that coast live oak seedlings and saplings have been found to be present or abundant in a wide variety of oak field surveys that occur in sites without Sudden Oak Death; the recruitment problem does not seem to affect coast live oak in the same way it affects valley or blue oak. Field surveys of blue oaks suggest low numbers of blue oak seedlings and saplings being recruited to adults (Swiecki et al. 1993). Valley oaks are often cited has having the lowest occurrence of seedlings and saplings (Tyler et al 2006); however, we found many small valley oak seedlings. These data suggest that valley oak acorns are at least germinating at high rates at Arastradero, although conditions are not promoting recruitment to adult age classes.

The relative frequency of plots with each species of oak saplings closely reflects the relative abundance of adult trees of the same species. In plots with saplings, 61% contained live oaks, 11% contained blue, and 28% contained valley oaks. With respect to trees, 57% were live oaks, 8% blue oaks, and 30% valley oaks. Thus, the three species are producing seedlings at rates equal to the presence of adult trees, but as noted before, blue and valley oaks were completely missing from the near or above browse height saplings.

Factors affecting Seedling Location

Of the 3 strata sampled, we found the tree strata, with an average cover of 44%, had the highest incidence of saplings compared with adjacent plots (11% cover) and grassland plots (2.5% cover). The obvious conclusion from this is that acorns tend to germinate in close proximity to their parent tree. This also suggests that Arastradero's saplings tended to grow the best underneath at least partial canopy. Literature supports part of this assertion. Moderate shade intensities tend to favor blue oak saplings because these oaks require less water and have high photosynthetic capabilities. Blue oak saplings can persist in partial canopy for several years until a gap in the canopy enables the oak to achieve adult tree status (Callaway 1992, Swiecki et al. 1993). The ability of coast live oaks to tolerate shade is also well documented in literature (Callaway 1992) and our analyses showed an association between increasing canopy and coast live oak sapling presence. Valley oak saplings are widely reported to be shade intolerant (Pavlik et al. 1991), however our data showed that plots with valley oaks were much more likely to occur in the tree strata. This discrepancy may be a result of the fact that most of the saplings we measured were newly germinated seedlings; these seedlings simply germinated by their parent tree and will likely not survive. Another study suggests that in mesic and fertile areas, a certain valley oak ecotype is more shade tolerant (Callaway 1992). In order to show this to be the case at Arastradero, we would need to gather more data about rainfall and soil type.

Proximity to shrubs may be important for some oak species. Analyses for coast live oak showed a positive association between sapling presence and shrub number. While other studies have found that coast live oaks develop well with the aid of a nurse plant (Pavlik et al. 1991), research is not so clear for blue oak. Callaway (1992) found that blue oak seedlings had higher survival rates when a nurse shrub was present. However, Bernhardt and Swiecki (2001) determined that while blue oak presence and shrub cover tended to occur at the same site, shrub presence did not necessarily facilitate blue oak growth. This is because the same factors that allow for a shrub understory also allow for blue oak sapling development (Bernhardt and Swiecki 2001). More research is needed to understand the association between shrubs and blue oaks. Valley oaks at Arastradero showed no correlation with shrub presence, which is supported by literature indicating valley oaks are shade intolerant plants (Callaway 1992).

We found that total sapling number increased with increasing litter coverage and found that live and valley oak sapling plots had much more litter than plots without saplings. Donath and Eckstein (2008) state that all oak saplings benefit from litter. Lack of litter puts seedlings at risk for high levels of herbivory and fatal levels of water loss; thus, oaks germinating in litter have higher rates of survival. This being said, too much litter can inhibit seedling growth by preventing seedlings from emerging.

We found no blue, few coast live, and few valley oaks in the grassland. This finding could be due to lack of canopy and all the benefits provided, but could also be due to the fact that California's grasslands contain a variety of non-native grass species. These invasive annual grasses could be competing with the oaks for water and other resources. According to Bernhardt and Swiecki (2001), many researchers believe there is much less soil moisture available in oak woodlands today, and that this is due to the replacement of native with non-native vegetation. In another study, Koukoura and Menke (1995) looked at the competition for water between a native perennial bunch grass, *Elymus glaucus*, and blue oak seedlings. They found that while aggressive non-native annual grasses can out compete the seedlings for moisture availability, native perennial grasses do not compete as much with the seedlings.

We found a small number of true saplings, >10 inches tall, and these plants provide insight into conditions that may support the transition from seedling to above-browse height sapling. True saplings were further from the nearest tree than small seedlings, which may result in less competition with large tress as they grow. They also occurred in areas with few gopher holes compared to plots with small saplings. Small rodents, gophers in particular, are widely recognized as major predators of oak seedlings (Griffin 1971, Davis, et al. 1991, Tyler, et al. 2002) and a main cause in lack of regeneration (Griffin 1971). Also, the percent of bare ground was much higher than in plots with small saplings. This increase in bare ground did not correspond to less grass, litter or shrub cover, so it is not clear what type of cover was replaced by bare soil. More information is needed on the differences in ground cover around large and small saplings.

Climate Change Considerations

Our study does not directly address the influence of climate change upon the oaks of the Preserve. However, the accelerating change in our global climate will undoubtedly affect all oak habitat in California. Climate change will alter both the biotic and abiotic conditions under which the current populations of our endemic oaks reside. Changes in precipitation patterns, prevailing winds, and temperature could have direct impacts on both the regeneration of the species as well as the survival of the extant adults. Recent modeling work has highlighted the potential shifts in plant communities in general (Ackerley), as well as California oaks in particular.

Using a variety of climate change factors as variables, several computer modeling studies have predicted shifts in habitat types in California on a landscape scale. Rehfeldt and others (2006) demonstrated an increase in montane and grassland habitats in California at the expense of arid woodlands, which includes the oak woodlands, with changing precipitation and temperatures. Bachelet et al. (2001) tested a variety of models used to predict future shifts in biomes based on both slight and extreme temperature increases. While not all models agreed, for the most part they predicted an increase in coniferous forests coupled with decreases in shrubland and savannah woodlands in our area. Adding fire into the models, Lenihan (2008) also predicted a decrease in the woodland/shrubland habitat type in California.

The movement of conditions suitable for valley and blue oaks has modeled by Krueppers et al. (2005) who predict a decrease of 59% in suitable blue oak habitat in California. Similarly, valley oak habitat showed a decrease of 54%. Suitable habitat moved north and higher in elevation in both models used in this study. Sensitivity to available moisture for both species appeared to be a significant factor in these shifts. These models predict only the potential suitable conditions for the major biomes and the particular oak species. The existence of these suitable abiotic conditions does not guarantee the existence of the plant communities on the sites. With the movements of animal and plant species, new abiotic and biotic pressures may be exerted upon the oaks. Plants with limited ability to rapidly disperse to more suitable areas are particularly sensitive to extinction under climate change.

As a result of these impacts to species and ecosystems, global climate change is likely to drastically alter the face of environmental restoration. The practice of recreating the historical habitat type on a particular site may become both unfeasible and unwise as the conditions change. Young (2000) suggests a shift towards restoration as a repository of biodiversity rather than simply recreating an ecosystem once present on a particular site. The practice of restoration may move to a more regional perspective, rather than a site-based activity. For example, Rice and Emery (2003) suggest regional seed mixes for blue oak restoration as a strategy to maximize the adaptive potential of the species. Grivet and others (2008) demonstrated the high genetic diversity in the oaks of the Bay Area, and this diversity will need direct preservation in restoration projects as well as other conservation activities.

RECOMMENDATIONS

General Recommendations

The results of our study and information from the literature suggest 4 courses of action to promote oak regeneration at Arastradero Preserve:

1. *Protect regenerating oaks*. We found many plots with newly or recently germinated oaks of all three species. These young plants will die or be eaten if not protected.
   - We recommend protecting a number of plots that have saplings with wire cages or tubes to allow growth of naturally-regenerating oaks. Focus on blue and valley oaks. We found only 8 plots with blue oaks and 20 with valley oaks. We recommend all these be protected with above ground and below-ground herbivore protection. The stands and plots with the blue oaks were: stand 5 in plots 4, 29, 47; stand 9/10b in plots 3, 6; stand 4 in plot 10; and stand 27 in plot 14. The stands and plots containing valley oak saplings were: stand 9/10b in plots 3, 6, 8, 10, 13, 17, 40, 42, 43, 45, 48, 54, 75; stand 18 in plots 8, 15, 19, 30, 69; and stand 21 in plots 17, 25. The maps in Appendix 4 show the locations of the plots and the number of samplings in each plot. Appendix 5 gives the actual UTMs for all the plots visited, so that plots can be located.
   - Above ground caging should be at least 48 inches tall; 60 inches is ideal. For below ground caging, material should extend 1-2 feet down to deter gophers from eating sapling roots. Cage multiple saplings, if appropriate.
   - Protect some of the coast live oak plots with true saplings. Saplings greater than 60 inches in height do not need protection. Live oak saplings between 24 and 36 inches that could be protected occurred in these stands and plots: stand 9/10b in plots 2, 6, 8, 17, 22;

stand 20 in plots 4, 8, 9, 10, 15; stand 2/3 in plots 30, 60, 65; stand 18 in plot 69 and stand 23 in plot 30. See Appendix 4 for the locations of these plots.

- Clearing away non-native grasses and leaving areas bare or areas covered with leaf litter may also promote survival. Our results suggest that bare ground of 10-20%, litter cover of 40%, and grass cover at 40% in the 5m radius around plants may benefit them. Potentially, saplings may benefit from having the grass cleared away nearer the plant.
- Sample more of the Preserve to find more blue and valley oak seedlings and saplings that could be protected.

2. *Plant blue and valley oaks*. Planting blue and valley oaks can also add to the stock of potential future trees. Planting acorns (rather than seedlings) and protecting all plantings with above and below-ground herbivore protection are strongly recommended (see next section on Planting Recommendations).
   - For blue oaks, plant acorns in/adjacent to blue and valley oak stands. We found no blue oak seedlings in coast live oak stands; they may be outcompeted by coast live oaks. Be sure the soil is well aerated. So, avoid compacted areas or mechanically loosen compacted soils.
   - For valley oaks, plant in and near valley oak stands. Since valley oaks require particular soil types and moisture conditions, the presence of existing oaks is a good indication the appropriate conditions exist. Plant acorns at varying canopy covers from about 40% cover to very little cover.
   - If moving oaks out into the grasslands is desired, try succession planting. Begin by planting coyote bushes, or other nurse bushes, into the grassland at varying distances from the edge of an oak stand. Once bushes reach a few feet in height, plant acorns near enough to the shrubs so that they receive about 40% cover. Sites with 8 gopher holes per 100 square foot plot or less are optimal for new plantings. Aerate compacted soils.
   - Monitor progress of the plantings and alter tactics based on what works well and what does not. Specific recommendations for planting and monitoring oaks follow.
   - Design and implement experiments testing different planting approaches based on monitoring results and literature findings.
3. *Plan for change*. There is no doubt that diseases and climate change and other unpredicted assaults will challenge oaks in the future. Experiment with planting a range of oak ecotypes

and planting them in regions that, in the future, may have conditions beneficial to oaks. Remain in contact with researchers studying oaks and climate change for the most relevant information, experimental approaches, and management strategies.

4. *Conduct more studies*. Also needed to manage oaks well are studies of:
   a) Soil type and moisture conditions most beneficial to oak survival.
   b) Succession planting.
   c) Survivorship of local oak ecotypes.
   d) Effects of native grasses on sapling growth and survival.
   e) Effects of goat grazing on grassland diversity and oak regeneration.
   f) Age structure of the Arastradero tree population and recruitment needed to compensate for tree death and to increase the oak population.
   g) Oak regeneration and habitat conditions at other sites in the region.

Planting Recommendations

Site Selection. Oaks are some of the most dominant trees in California, but years of human impacts have hurt many species. As a result of these impacts, restoration is needed in the forms of planting and maintenance. Prior to any type of activity regarding the planting or growing of oak species, one must choose the optimal site that will maximize both yield and heath for the acorns and saplings. Typically, sites for restoration should be well within the range of conditions for the specific oak species being planted. It is important to assess the quality of the sites including soil type, topographical factors (aspect and slope), current vegetation populations, and overall health of oak trees in the immediate vicinity (Morrissey et al. 2007). Soil moisture and canopy cover are important factors in oak germination and growth; optimal conditions for these factors vary by species. Huang et al. (1997) found, in general, that soils beneath tree canopys had greater concentrations of organic matter and nutrient cycling, which produced enriched soils and enhanced fertility of oak trees. Competition by other species should also be evaluated. For example, areas where an abundance of small oaks are already growing are not ideal as regeneration is already occurring. Regeneration is difficult in areas where above- and below-ground herbivory is prevalent. When feasible, avoid areas that have high rates of herbivory.

In addition to these basic recommendations, restorationists need to plan for climate change, which can alter and possibly ruin restoration efforts. One restoration strategy to consider is planting at multiple sites including some at the extreme edges of the range or areas where oaks are likely to migrate as temperature and rainfall change. These sites will need monitoring over a period of 20+ years to see the response of plantings. Also, experiments are needed regarding moisture levels, rainfall, temperature, amount of shade and sunlight received, and changes in invasive, and non-native plant ranges as climate changes. For example, Devine et al. (2007) found that under drought growing season conditions, such as is predicted by climate change scenarios, control of competing vegetation was important for increasing growth of oak seedlings, and irrigation was an effective supplement to vegetation control during the first year of establishment.

In choosing a site, avoid areas where Sudden Oak Death exists. In addition to killing coast live oaks, Sudden Oak Death has changed the composition of the species in the infected forests, reduced ecosystem functionality, changed wildlife composition and changed fire frequency (Rizzo 2007).

At Arastradero, cattle grazing is not a problem as it is in other areas. However, Arastradero managers may want to avoid planting in areas heavily impacted by former horse ranching activities. By carefully selecting planting sites, managers can reduce the need for site preparation. However, oak growth may be promoted by removing non-native plants and weeds using targeted grazing, mowing and application of herbicides. Once the unnecessary plants have been removed, soil preparation may be considered. Possible actions can include mulching, use of organic soil nutrients in areas lacking the necessary ones, tilling of the soil, or even controlled burns to open up acorns that may have fallen on the ground (Plumb and De Lasausx 1997).

Planting and maintenance. Valley, blue, and coast live oaks all require nutrients, shelter and water for germination of acorns into seedlings. Researchers have tested a number of planting methods including ways of protecting acorns and seedlings from herbivory and plant competition, adding nutrients naturally or chemically, and different watering regimes including length of time and amounts of water.

Planting acorns has benefits over seedlings. Tietje et al. (1991) examined whether planting acorns at different depths would increase the survival rate of oak seedlings. Acorns were planted at depths of 1.3, 5.1 and 10.2cm, with a depth of 5.1cm (2 inches) producing the best results in terms of viable seedlings. Alternative planting methods include well-tilled seedbeds covered with soil (about 2 inches) and a layer of mulch or straw for protection from deer and rodents.

The effect of irrigation on the growth of oak trees has been investigated extensively. Results vary but many researchers have found seedlings benefit from watering during the first year of growth. One research project incorporated four experiments over a ten year period to determine interspecies and intraspecies water use characteristics; results showed the use of irrigation produced positive height growth in seedlings and limited height growth for seedlings not watered regularly (Struve et al. 2006). The University of California Bay Area Research and Extension Center in Santa Clara California investigated the effect of irrigation on the growth of oak trees for a four-year period. Costello et al. (2005) irrigated three species of oaks at three different levels and found no significant differences in the trunk diameter. However, they did find after 4 years of treatments that the *Q. agrifolia* grew larger than both *Q. lobata* and *Q. douglasii* and developed a stronger vertical than horizontal orientation (Costello et al. 2005).

Mulching can help reduce soil moisture loss. Devine et al. (2007) demonstrated that mulch increased soil water content and seedling height by 56% compared to a one-time removal of competing vegetation. Mulch decreases evaporation of water from the soil and controls the amount of weed growth. Irrigation did increase survival but was an expensive technique (Bernhardt and Swiecki 1991). Weekly irrigation of 3.8L per seedling increased seedling growth only where mulch was applied and only in the first-year (Devine et al 2007). Fertilizer applied where planting did not increase seedling growth.

Tree shelters, cages, or tree tubes are essential for sapling survival. Tree shelters are comprised of a double walled translucent tube, which both protects and shelters individual seedlings (McCreary et al. 2002). Several studies performed by McCreary et al. (2002) have shown that tree shelters increase the growth of oaks as did a study at Arastradero Preserve (Hong 2000). The negative side to tree shelters is that they reduce initial stem diameter growth resulting in trees that are generally tall and narrow making them more susceptible to environmental conditions and wildlife (McCreary et al. 2002). Environmental conditions within a tree shelter are different from normal conditions outside of a tree shelter; tree shelters generally have higher levels of CO_2, higher temperatures, and higher humidity (McCreary et al. 2002). “Solid-walled tree shelters reduced browse damage and increased mean annual height growth compared to mesh tree shelters and no shelter by averages of 7.5 and 10.9cm, respectively

(Devine et al 2007)." If tree shelters are used it would be wise to place a stake next to the sapling to allow the base of the tree as well as the root system grow and become strong enough to support the increased height of the sapling due to the effects of the tree shelter. It is crucial not to remove the stake too early when the tree is not ready to withstand adverse environmental conditions. It is also important to make sure the tree shelters drain properly to ensure water does not build up within the tube. Holes at the bottom of the tube may be needed for proper drainage and increase acorn survival.

The use of small mammal exclosures has proved to be an effective method when increasing sapling survival rates. One study by Plumb and Hannah (1997) indicated an 80% survival rate with small mammal exclosures. Deer exclusion cages also produce a dramatic increase in sapling survival. Any type of cage proves to be an effective method for increasing sapling survival.

Monitoring Recommendations

Monitoring is crucial in determining the success or failure of an oak restoration project. It provides information on plant responses to management and natural conditions and allows managers to consider whether action is needed to rectify problems. The data collected can also be useful for future projects at the site or other similar sites. Monitoring can improve our ecological understanding of natural systems and gives managers information on what restoration goals may or may not be feasible.

Monitoring systems must begin with clear restoration goals and outcomes. Goals typically include ecological targets, such as rate of tree survival, and social targets, such as number of volunteers per year engaged. To be useful, these targets must be clear, measurable, and tangible. Targets should include the specific parameters to be measured, how the data will be collected, and how they will be analyzed. Monitoring should collect both qualitative and quantitative data.

Qualitative data are not amenable to statistical analysis but are easy to collect and can give a rapid assessment of basic conditions at the restoration sites. Such data can include counts of trees alive and dead, information on blooming and acorn production, and observations of herbivores. Collecting quantitative data requires a study design and adequate data to perform statistical tests. "The design of any data gathering or long term monitoring program must balance the need to be consistent over time to allow for comparison, but must also be flexible enough to accommodate changing circumstances and dynamics" (Tuazon 1991). It is also important that the data collection be as precise as possible. "The more precise or reproducible the result, the more reliable or accurate the result" (EPA 1996). For oak woodland monitoring, a list of what qualitative and quantitative data is listed below in Table 2. This represents a wide range of factors that can be monitored to assess the success of planting programs or the health of naturally-regenerating trees.

Both qualitative and quantifiable data must be careful recorded and stored in a database to allow long-term tracking of conditions and statistical or other summary analyses of data. According to Reiner et al. (2002), monitoring results are often wasted if they are not organized properly. The most successful monitoring programs are well organized, and regularly inform managers on the monitoring results (Reiner et al. 2002).

To ensure data are collected and analyzed correctly managers must develop protocols that describe data gathering, entry, and analysis standards. Protocols ensure monitoring are credible and will stand up to review by outside sources. Study designs and monitoring protocols should go through testing and evaluation of their effectiveness prior to being used for long-term monitoring (Oakley et al. 2003). Protocols should focus specifically on the project's restoration goals so that extraneous information is not collected and money is not wasted. These guidelines can apply to both naturally-growing oaks and oaks planted as part of a restoration project.

Finally, a well designed monitoring program will also identify when and how long to monitor, who will do the work, as well as how much the program will cost and sources of funding.

What to Measure and How Long. Once project goals, clear targets, and related protocols are established monitoring can begin. The parameters monitored must directly assess the project's targets. For example, if a project target is to have 20% of its planted trees reach 5 feet tall, then clearly monitoring will include measuring the heights of all trees planted. Table 5 gives list of typical qualitative and quantitative parameters. Combining these variables with aerial photographs, that can be manipulated with GIS, would provide a thorough representation of the oaks (Gaman and Casey 2002). While it is tempting to list a great array of parameters for monitoring, monitoring takes time, money, and expertise. The parameter list should be as lean as possible while still providing adequate data. Also, if a project is using volunteers for monitoring, "as a general rule, it is a good idea to start small and build to a more ambitious project as your volunteers and staff grow more experienced" (EPA 1996).

Table 5: Qualitative vs. Quantitative Parameters for Monitoring Oaks

Qualitative	Quantitative
Vegetation Survey to Compare to Baseline/as Built Survey	Litter Cover
Dominate Plant species	Height of Saplings
Presence of Invasive/Nonnative Species	Basil Diameter
Wildlife Use of Site	Diameter at Breast Height (DBH)
Soil texture and color	Number of Saplings Planted/ Regenerated
Fixed Point Photographs	Distance To Nearest Tree of Same Species
Rainfall and Water-level Data	Height of Adult
Indications of Human Use	DBH of Adult
Signs of Herbivory	Distance to nearest Shrub
Health	Distance to Nearest Tree
	Distance to Nearest Stream
	Canopy Cover
	Slope Aspect
	Soil Depth
	Soil Moisture
	Density of Gopher Holes

In general, oaks need to be sampled only once a year when the trees are flowering in the summer months (USDA 1991, Nickles 1996). Ideally, seedlings should be monitored until they become saplings taller than browse height (60in) and have produced acorns. Short term monitoring of 5 years or less is used to make field level decisions with limited information.

Longer term monitoring can provide information on changes in the range, status, and condition of the oak woodlands, which allows managers to make more educated decisions (Tyazon 1991). Ideally, oak woodlands should be monitored for as long as possible, perhaps every few years, to observe long-term changes, such as those due to climate change. However, each project is different and has its own constraints that limit monitoring time. When planning how long an oak woodland site should be monitored, it is important to take into account budget and resources. Monitoring can be an expensive process and require lots of equipment and many workers.

Who Can Do the Work. Throughout the monitoring process, a variety of people can be involved depending on the range of responsibilities and difficulty levels. Having dedicated staff is critical for continuity. Researchers and experts, including natural resource scientists, university professors, as well as university students, should be involved in order to assure that monitoring is being done scientifically to provide the data needed. Volunteers are also extremely beneficial to the success of monitoring and they are a mainstay of the work at the Arastradero Preserve. Local community groups, high school students, and willing community members can all make can be terrific volunteer monitoring data collectors because they do not need to be funded, they are usually happy and eager participants, they learn about the environment while helping, and they gain a sense of community stewardship.

Getting a variety of people involved can be quite beneficial. Each individual can contribute differently and learn to appreciate the project. “Communication and collaboration between community groups, land managers, and scientists, has the potential to greatly benefit all parties as well as the resource itself (Ballard et al. 2002).” By involving the local community, people become attached to the site and learn to care for it. “Collaborative management and participatory monitoring projects are based on the notion that conservation and resource management are most effectively executed when local people participate in the management and monitoring of the biodiversity and natural resources” (Ballard et al. 2002). Both the environment as well as the people involved can benefit from monitoring participation. For example participants on an oak restoration project in Willow Glen “stated that they learned where they might need to target their oak restoration efforts, and got a better idea of the value and limitations of a scientific monitoring program. The scientists found that they learned about the goals and abilities of local citizens and had to re-examine some of their own assumptions. The City managers stated that they gained insight into priorities of preserve users and knowledge of areas that might require new management efforts" (Ballard et al. 2002). When a variety of people get involved in the monitoring process, the project becomes an integrated learning tool for everybody and brings a variety of perspectives and ideas to the project.

Identifying a range of stakeholder groups is an effective first step in recruiting volunteers. Stakeholder groups such as individual community members and groups, nearby landowners, government agencies, environmental and conservation groups, academic institutions, businesses, and people who use the areas or similar areas for recreation should all be identified. These stakeholder groups may be the ones that will ultimately be affected or interested in the restoration project because of the aesthetics, recreation, influence on local economies, commodity use, jobs, implementation of policies, or its effects on the health and condition of the environment. Many of these stakeholders choose not to volunteer based on time constraints or bad past experiences with outdoor group projects. One way to get these stakeholder groups involved is to engage local leaders and have them participate in the volunteer restoration project (US Forest Service 2003).

The reasons why volunteers participate vary, but many of them hope to educate themselves and be able to educate others about oak restoration and ecology. It is good to take this into consideration when recruiting volunteers so that you can promote it as one of the goals and outcomes of the volunteers' experience.

Training. For volunteer monitoring to be effective, volunteers must be carefully trained and supervised. Though using volunteers has many perks, using volunteers can cause people to question the credibility of your data (EPA 1996). Therefore, effective training, clear guidelines and expectations, and quality control are all critical. Effective training begins with a project description and history of the site to give to the volunteers background into why the restoration project is important (EPA 1996). The heart of volunteer training is instruction on data collection, which requires clear written protocols and adequate time to physically practice using the equipment and collecting the data (EPA 1996).

A clear and detailed set of training protocols is essential for obtaining high-quality data. Protocols will standard sets of measurements and quality. A series of standard operating procedures should present the details on how to carry out all aspects of the monitoring.

Procedures should be written to give detailed, step-by-step instructions for each procedure (Wieringa et al. 1998). Volunteers should be informed which measurements are essential and which are not as critical, so they know how to prioritize their time (EPA 1996). Volunteers may not collect as many samples as were planned due to time constraints or just lack of experience. To accommodate for this, it is always good try to have volunteers take more samples than actually required. Once the procedures have been established, it is important to regularly plan times to recruit and train volunteers, because volunteers often only participate in projects for brief periods (EPA 1996). Long-term volunteers can participate and help lead new trainings to keep their skills sharp. Also, these long-term volunteers can be inspirational for new recruits and excellent sources of information on field conditions and what works best in the field.

Finally, to ensure high quality data, staff or managers must review each step of the volunteers' work for quality control and to be sure all data are collected in a consistent manner that follows the data collection, entry, and analysis protocols. If there are digressions, conduct short updates with volunteers to correct errors. If digressions are significant and/or systematic, protocols should be revised and volunteers retrained in the aspects requiring attention.

ACKNOWLEDGEMENTS

We are grateful to the Arastradero Preserve managers, Sheri Lubin, Director of Stewardship Programs, and Miriam Sachs-Martin, Chief Steward, for all the time and support they provided us as we undertook this process. We also thank Cyrus Hyatt, GIS expert for Acterra, for his invaluable help with GIS layers and information. Thanks also to Dr. Rich Taketa, Geography Department, and Dr. Will Russell, Environmental Studies Department, for lending usfield equipment. And, a special acknowledgement to Matt Leddy, professor of horticulture at the College of San Mateo, for all his assistance in helping us identify trees and new recruits.

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Appendix 1: Protocols for Field Data Collection

Top of the Data Sheets:

- Fill in your names, circle the stand type, and write in the stand number. Put the date and time you arrived and left.
- If it takes more than one visit to finish the stand, record each date you collected data, with arrival and departure times.
- Fill in this information on all pages of all forms.

For Each Plot on the PLOT DATA FIELD SHEET:

<u>Page 1</u>

- Find the GPS coordinate point for the plot and mark that point with a flag. Measure 5 meters out from the flag (half the rope length) and make a circle using flags around the coordinate point to form your plot boundaries. Thus, your plot will be 10 m in diameter.
- Record the GPS coordinates of the center point as given on the GPS unit. The Garmin units give the error, so record that number for those units.
- Measure canopy cover at the middle point of the plot using the Spherical Densiometer. Make sure the unit is level and record the number of squares in which you saw canopy. Multiply that number by 4 to get the percent cover. *All members of the team should take this measurement and then compare until you all are close in your estimate. After that, just one person can take the measurement.*
- Determine the slope from the middle point of the plot. List the slope as steep, moderate, slight, or flat.
- Measure the aspect (direction that the sun would hit the slope) in degrees using the compass from the middle point of the plot.
- Count number of saplings of each species. If you don't know the species of a plant, take a photo of the plant with leaves and buds, for later identification. Be sure to put the photo number or other identifier on the data sheet.
- Use the soil corer to measure soil depth and note the soil type based on the material in the corer. Soil types include rocky, organic, sandy, and high mineral content.
- Count the number of gopher (small 2-3 inch) and ground squirrel (4-5 inch) holes within the boundaries of the plot.

<u>Page 2</u>

- Look at the entire plot and estimate the amount of coverage by shrubs, grasses, litter and bare soil. Record your estimate to the nearest 5 or 10%. Together, these should add up to 100% of your plot. *All members of the team should take this measurement and then compare until you all are close in your estimate. After that, just one person can take the measurement.*
- Record the number of all trees in the plot. Be sure to identify the number and species of oak trees. Record the number of other species and identify the species, if you can.
- Record the number of shrubs and identify the species, if you can.

- Note any other comments or observations about the plot.

For Each Sapling in the Plot, use the SAPLING DATA FIELD SHEET:

- Note the species of the sapling you are measuring and give the GPS coordinates of the plot in which the sapling occurs.
- Measure the height of each the sapling to the nearest 0.5 cm. The measuring tape you have is in inches, so you will need to convert to cm.
- Measure basal diameter of each sapling to the nearest 0.5 cm. Convert from inches to cm.
- Measure the distance to the nearest shrub and to the nearest tree (convert to meters).
- Measure distance to the nearest tree of the same species, if that was not the nearest tree.
- Measure the canopy cover over the sapling using the Spherical Densiometer.
- Note signs of herbivory or girdling using H for herbivory, G for girdling, Y for yes and N for no. For example: H = Y; G = N
- Note the health of the sapling (alive or dead) and any other relevant information.
- Note any other comments or observations about particular saplings.

For Adult Oaks in the Plot, use the ADULT TREE DATA FIELD SHEET:

- Record the GPS coordinates of the plot.
- Note the species of each oak tree. Take a photo if you don’t know, for later identification.
- Measure the height of each oak tree using the clinometer. Record the degrees to the top of the tree and the distance you are standing from the tree. Later, calculate the height.
- Measure DBH of each oak tree. For multi-trunk trees, measure the 3 largest trunks and note the total number of trunks.
- Note the health of the oak tree (alive or dead).
- Make any comments or observations on the oak trees.

Appendix 2: Data Sheets

PLOT DATA FIELD SHEET (page 1)				**Field Crew:**				**Date and Time (arrive + leave):**			
STAND TYPE:		Live Oak	Valley Oak	Blue Oak		**Stand Number:**					
Plot #	**Coordinates UTM-X; UTM-Y**	**Strata**	**# LO Saplings**	**# BO Saplings**	**# VO Saplings**	**Canopy Cover (# of squares)**	**Soil Type**	**Soil Depth**	**# Gopher Holes**	**Aspect (degrees)**	**Slope**
1		Trees									
2		Trees									
:		:									
:		:									
10		Trees									
11		Adjacent									
12		Adjacent									
:		:									
:		:									
20		Adjacent									
21		Grass									
22		Grass									
:		:									
:		:									
30		Grass									

PLOT DATA FIELD SHEET (page 2)						**Field Crew:**		**Date and Time (arrive + leave):**
STAND TYPE:		Live Oak	Valley Oak	Blue Oak		**Stand Number:**		

			Percent of Entire Plot Covered By:						
Plot #	**Coordinates UTM-X; UTM-Y**	**Strata**	**Shrubs**	**Grasses**	**Litter**	**Bare Soil**	**# of Trees (spp)**	**# of Shrubs (spp)**	**Comments**
1		Trees							
2		Trees							
:		:							
:		:							
10		Trees							
11		Adjacent							
12		Adjacent							
:		:							
:		:							
20		Adjacent							
21		Grass							
22		Grass							
:		:							
:		:							
30		Grass							

SAPLING DATA FIELD SHEET		**Field Crew:**		**Date:**	

STAND TYPE:	Live Oak	Blue Oak	Valley Oak		**Stand Number:**	

Plot #	Plot Coordinates	Species	Basal diameter (in)	Height (in)	Distance to shrub (ft)	Distance to tree--any (ft)	Distance to tree--same spp (ft)	Canopy Cover	Herbivory/ Girdling	Health

ADULT TREE DATA FIELD SHEET	**Field Crew:**		**Date:**	

STAND TYPE:	Live Oak	Blue Oak	Valley Oak	**Stand Number:**	

Coordinates	**Species**	**DBH (in)**	**Height (m) (degrees + dist)**	**Health (alive, dead)**	**Comments on Trees**

Appendix 3: Protocols for Data Entry

- The data entry spreadsheet has three worksheets, for plot data, sapling data, and tree data.

- Use the exact codes and categories given here. If you think a code or category does not work, please ask me about that. Please don't arbitrarily use a different notation.

- On the plot data spreadsheet, all data for a single plot must go on a single row. On the sapling and tree spreadsheets, all data for a single individually must go on a single row.

- Remember "0" is a number and a measurement! It does not mean no data. If you have no data for a column, leave it blank.

- Stand Type should be recorded as: tree, adjacent, or grass

- Field Crews are as follows: JAR (Jen, Ashley, Ricky), DJKM (Danielle and company), GMS (Gizelle, Melissa, Suzie), GWS (Galli, Whitney, Sidra)

- Soil Type is: organic, rocky, sandy, clayey

- Slope is: steep, moderate, slight, or flat

- Herbivory and Girdling are: y (yes) or n (no).

- Health is a (alive), d (dead), p (alive but in poor health—this is for individuals that have a very *obvious* problem such as covered with a pest, >50% dead leaves, etc.)

- Canopy cover is the number for the percent cover you measured. If you took 4 measurements at one location, the % cover is the sum of those 4 measurements. If you took only one measurement, then multiply that by 4 to get % cover.

- Oak species are LO (coast live), BO (blue oak), and VO (valley oak)

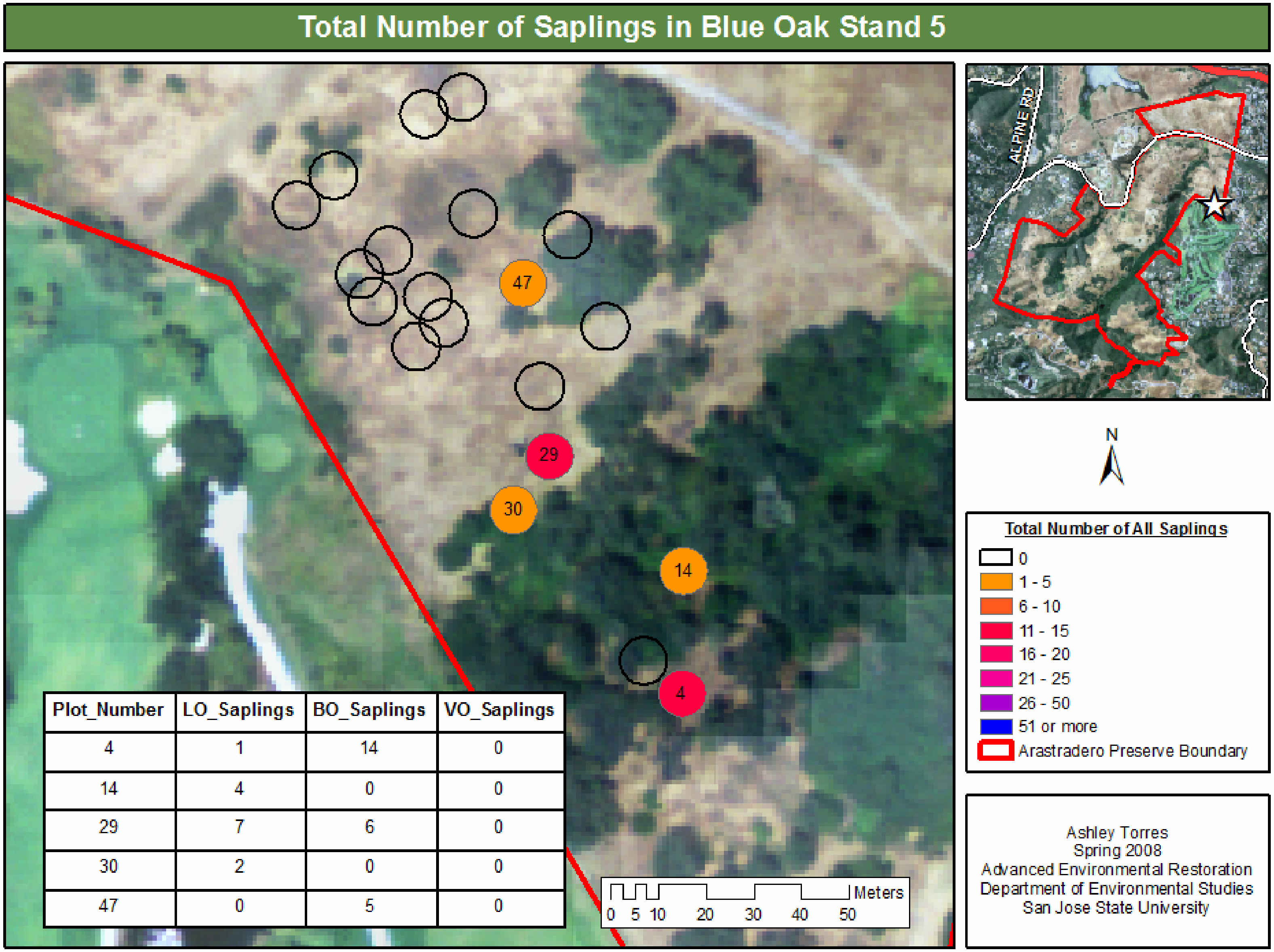
- All sapling height and diameter measurements are in inches to the nearest 1/4 inch. Record numbers using decimals, such as 1.25 (for 1 and a quarter inches).

- For plots where there were many saplings that you did not measure, you recorded the number of saplings that were small, mid-sized, or tall. Record that number in the "Number Saplings Similar Height" column. If you measured all the saplings in the plot, leave this column blank.

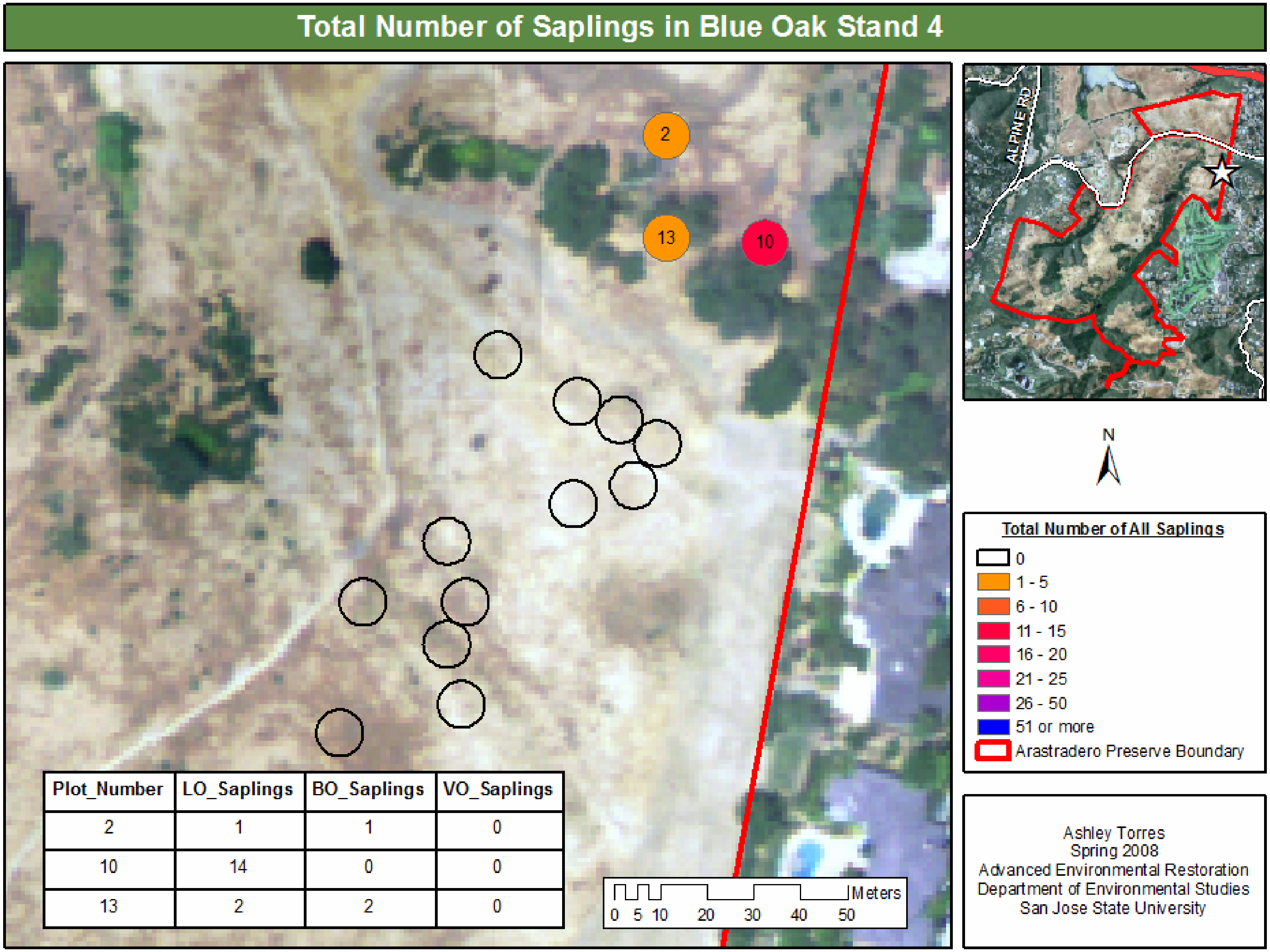
- Tree DBH is in inches to the nearest quarter inch. Tree height is in feet, to the nearest quarter foot (use decimals), if possible with the clinometer. Otherwise, to the nearest foot is fine.

- Long distances are in feet to the nearest quarter foot. Record numbers using decimals, such as 35.75, for 35 feet 9 inches (35 and 3/4s of a foot

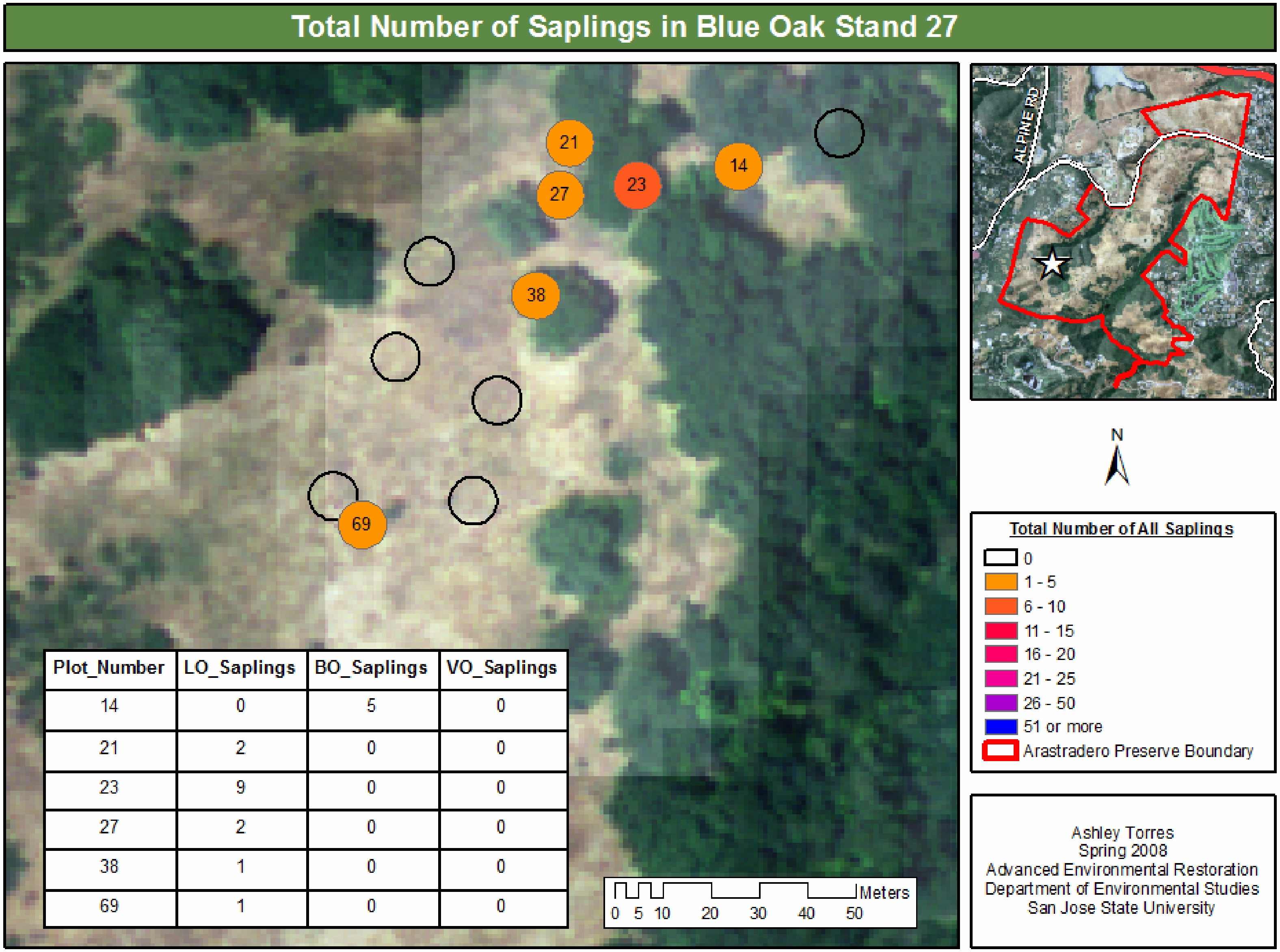
Appendix 4: Total Number of Saplings and By Species for Each Stand Sampled (total of 10 stands)



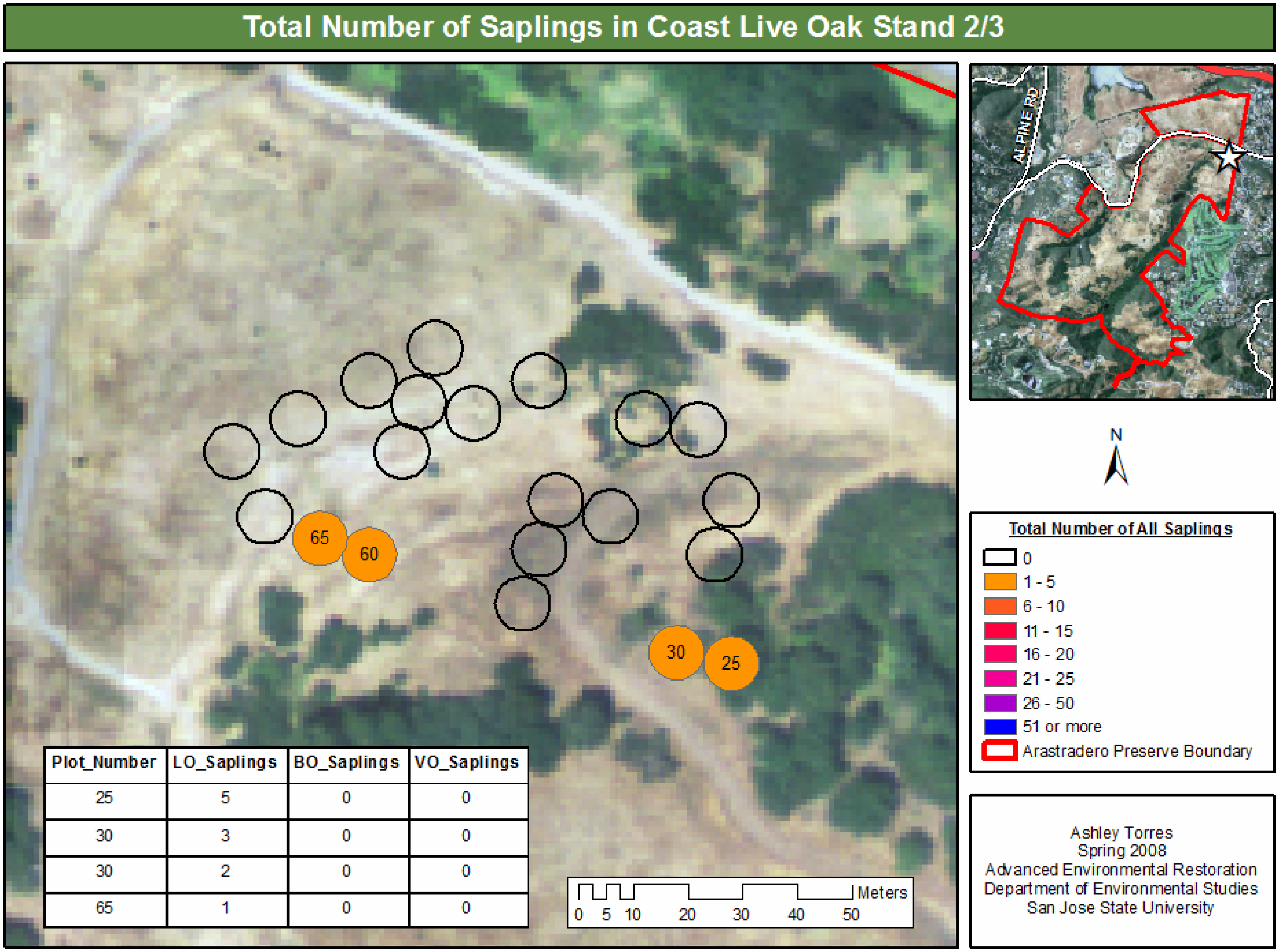
Plot_Number	LO_Saplings	BO_Saplings	VO_Saplings
4	1	14	0
14	4	0	0
29	7	6	0
30	2	0	0
47	0	5	0



Plot_Number	LO_Saplings	BO_Saplings	VO_Saplings
2	1	1	0
10	14	0	0
13	2	2	0

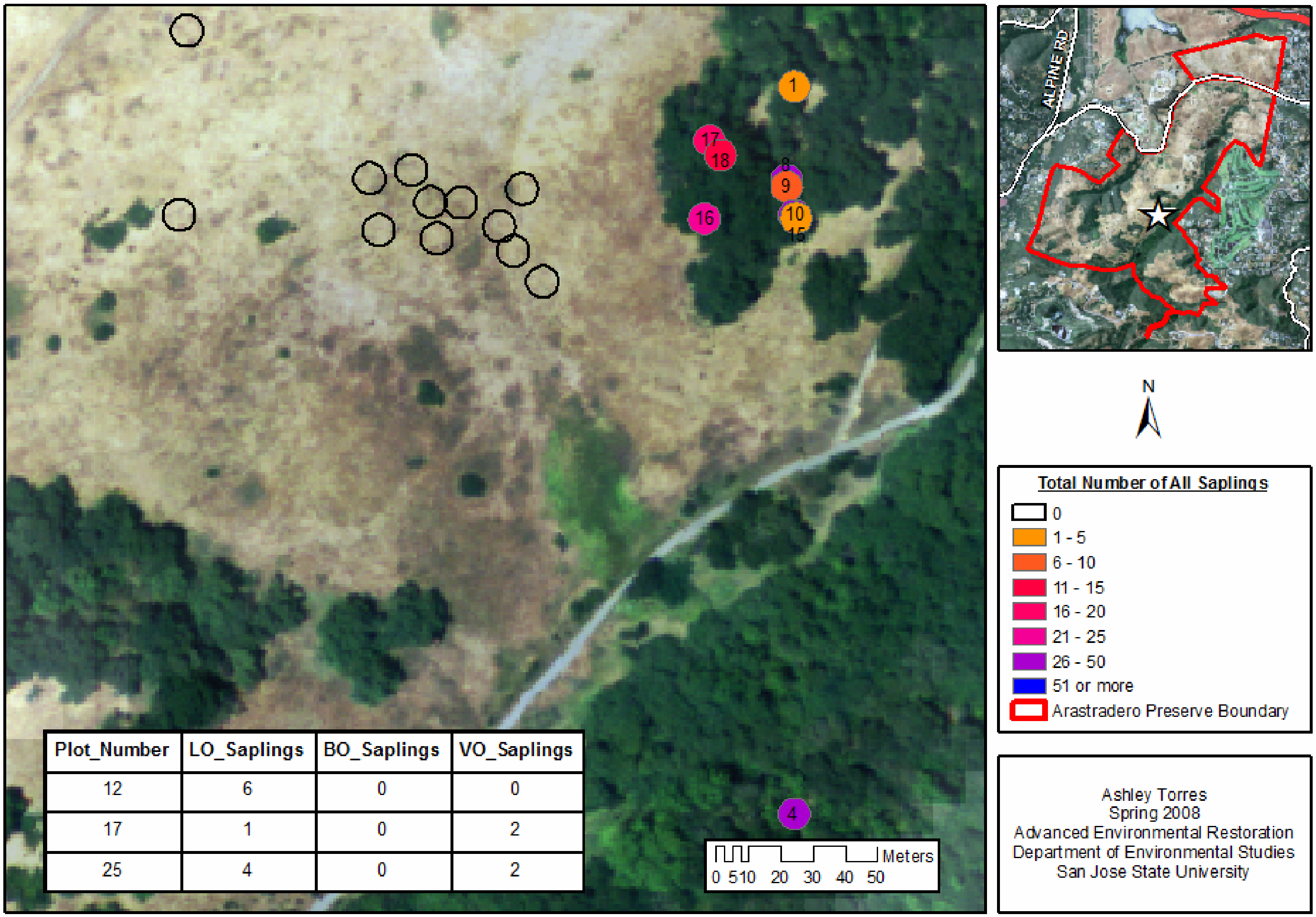


Plot_Number	LO_Saplings	BO_Saplings	VO_Saplings
14	0	5	0
21	2	0	0
23	9	0	0
27	2	0	0
38	1	0	0
69	1	0	0

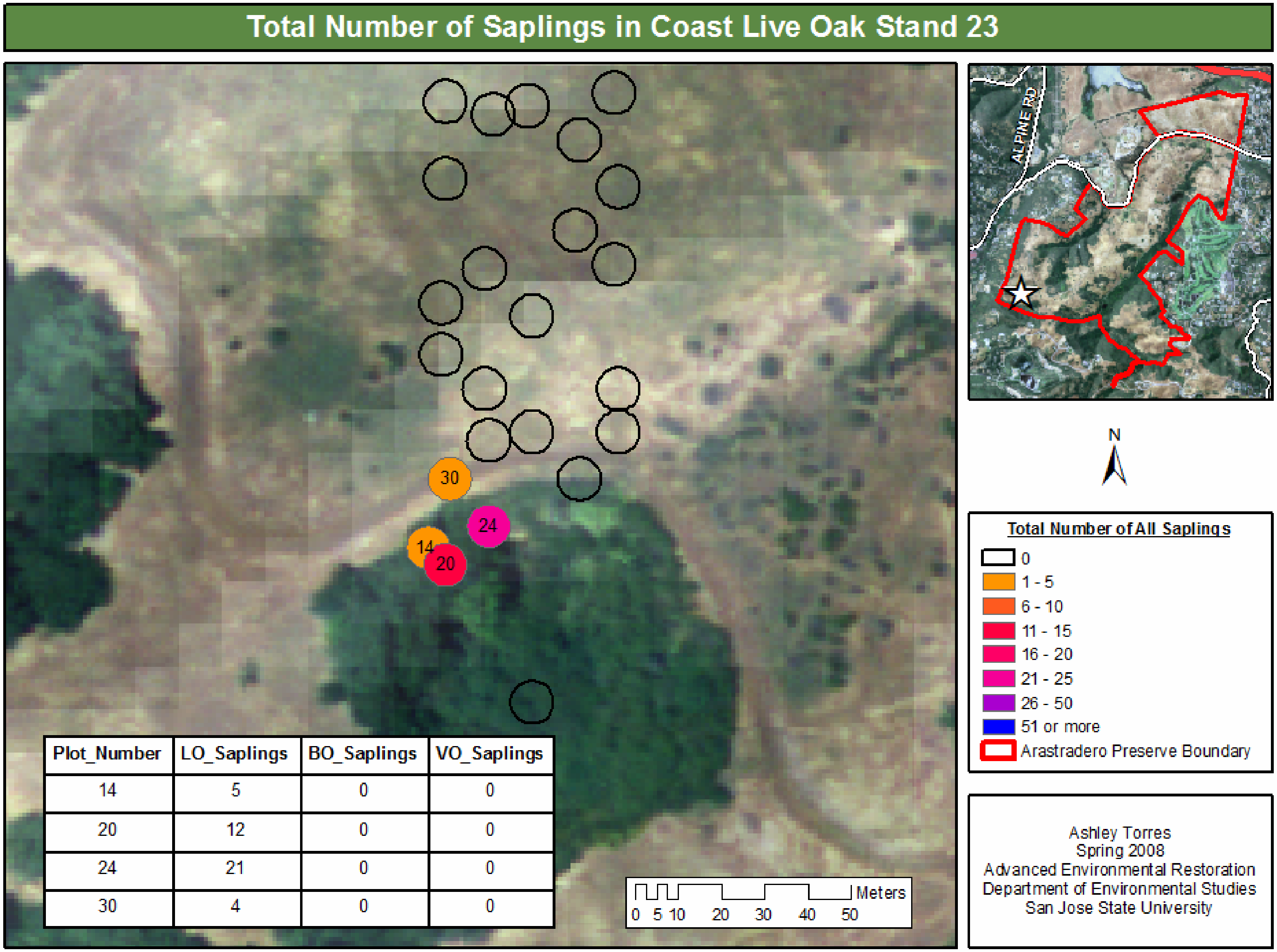


Plot_Number	LO_Saplings	BO_Saplings	VO_Saplings
25	5	0	0
30	3	0	0
30	2	0	0
65	1	0	0

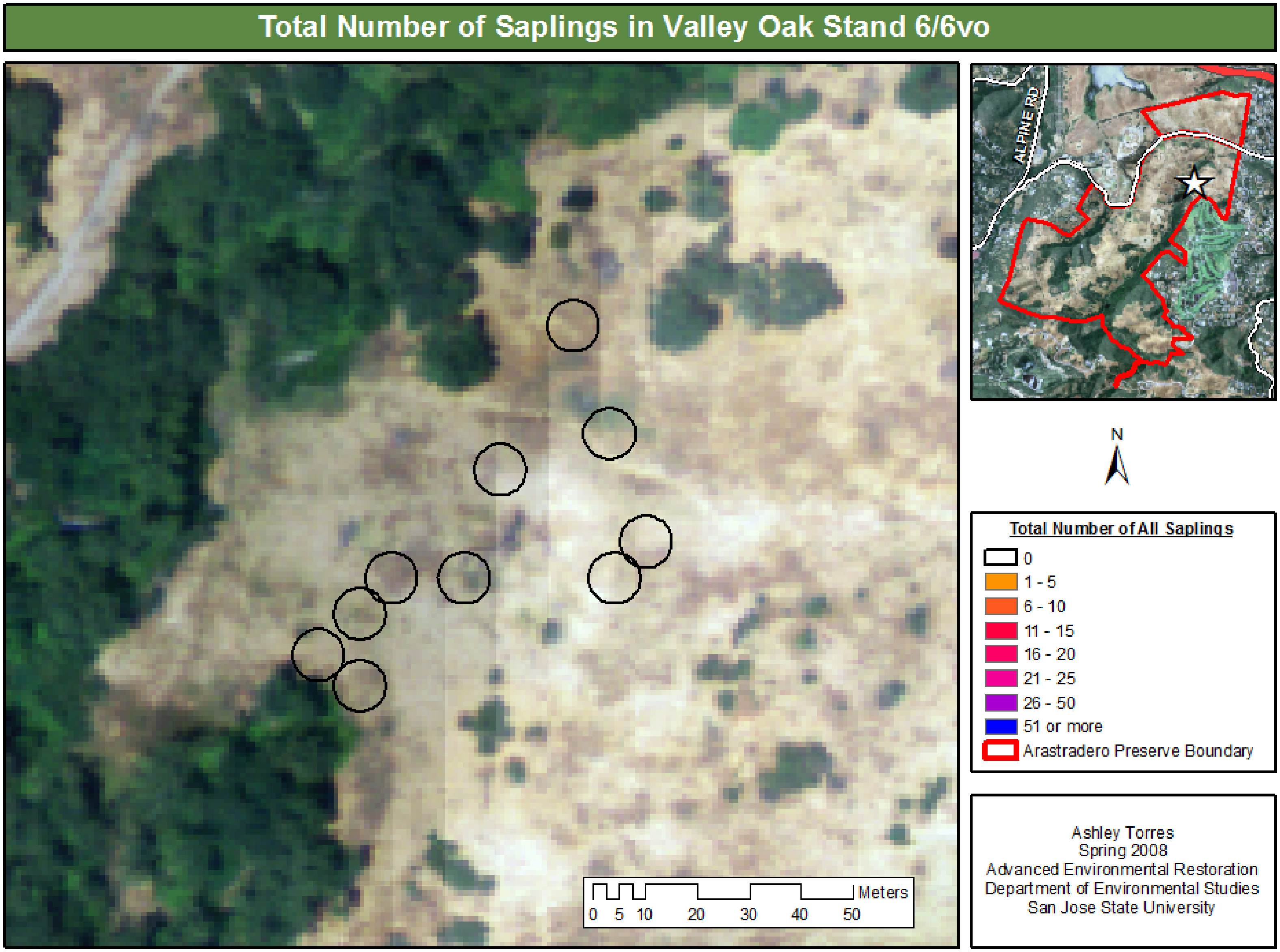
Total Number of Saplings in Coast Live Oak Stand 20

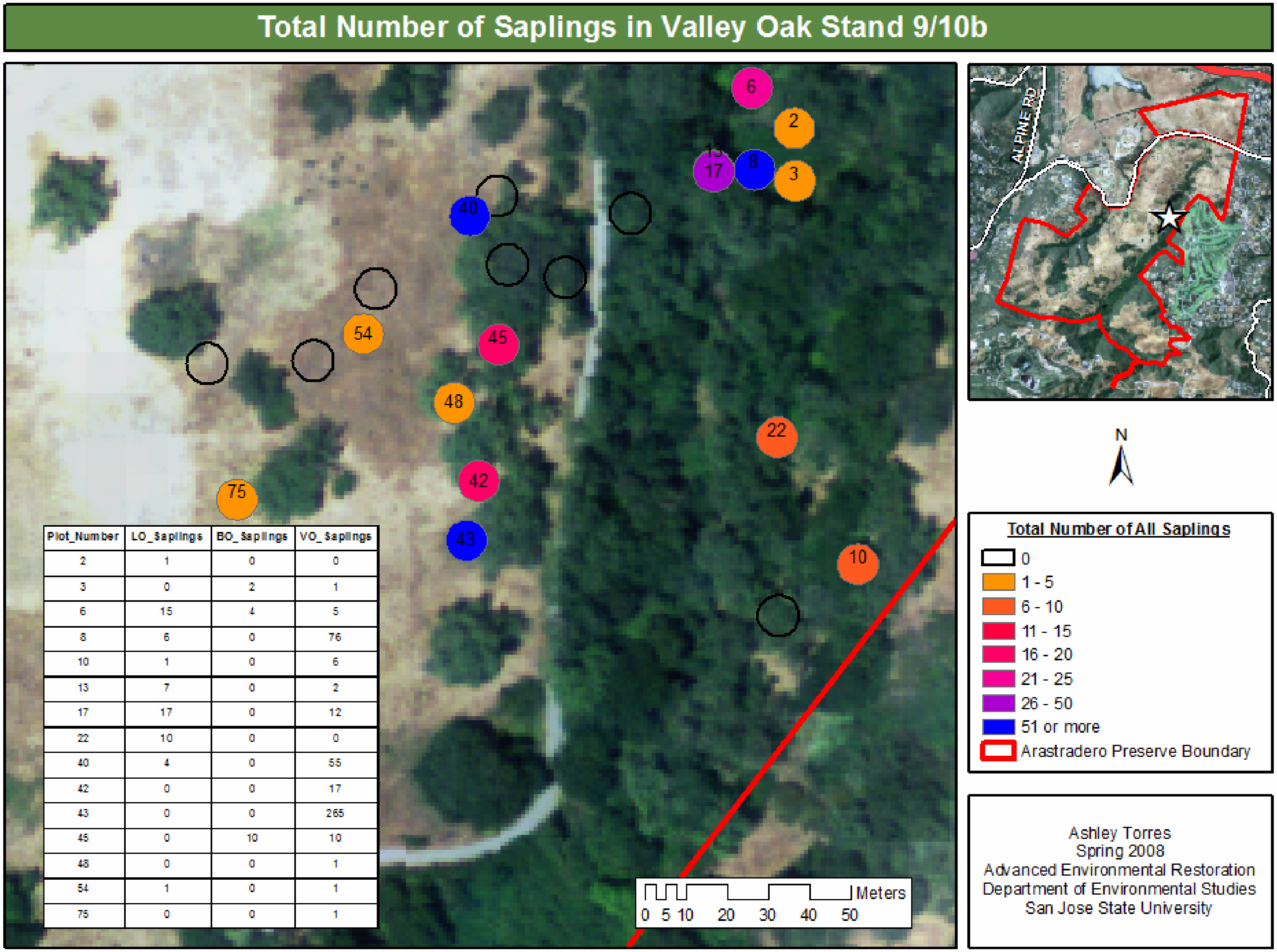


Plot_Number	LO_Saplings	BO_Saplings	VO_Saplings
12	6	0	0
17	1	0	2
25	4	0	2



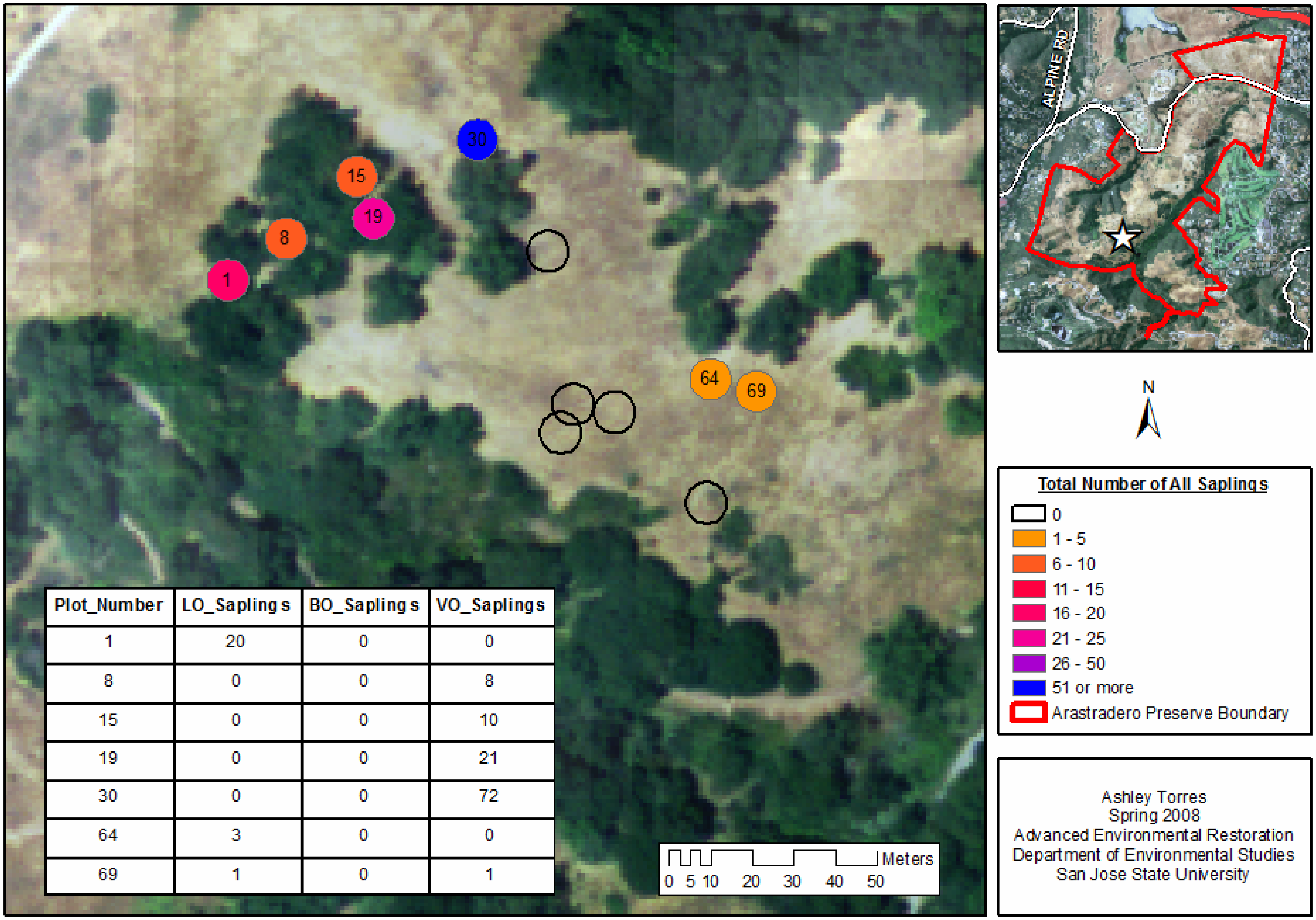
Plot_Number	LO_Saplings	BO_Saplings	VO_Saplings
14	5	0	0
20	12	0	0
24	21	0	0
30	4	0	0


Total Number of Saplings in Valley Oak Stand 6/6vo
ALPINE RD
N
Total Number of All Saplings
0
1 - 5
6 - 10
11 - 15
16 - 20
21 - 25
26 - 50
51 or more
Arastradero Preserve Boundary
Ashley Torres
Spring 2008
Advanced Environmental Restoration
Department of Environmental Studies
San Jose State University
0 5 10 20 30 40 50 Meters

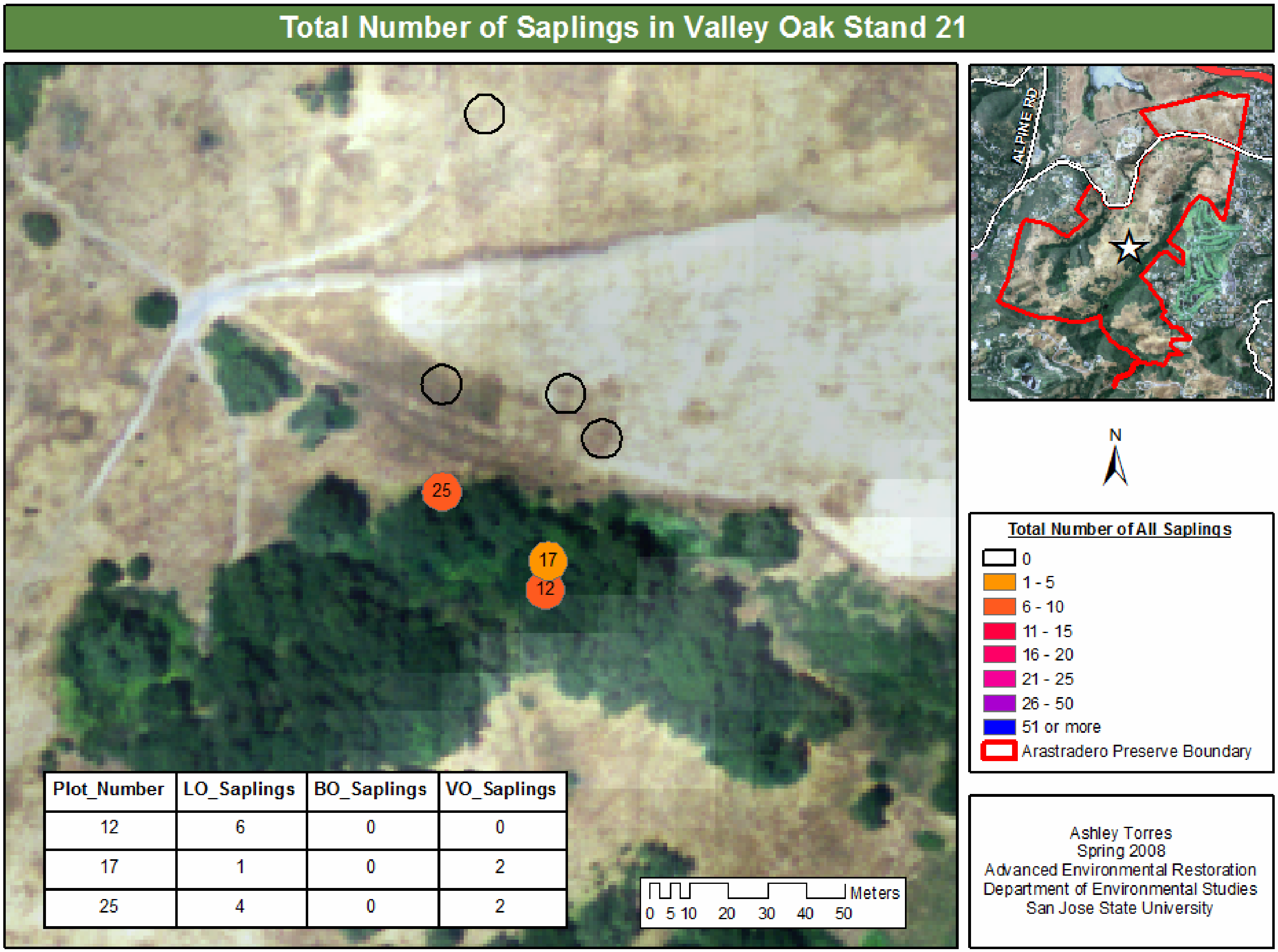


Plot_Number	LO_Saplings	BO_Saplings	VO_Saplings
2	1	0	0
3	0	2	1
6	15	4	5
8	6	0	76
10	1	0	6
13	7	0	2
17	17	0	12
22	10	0	0
40	4	0	55
42	0	0	17
43	0	0	265
45	0	10	10
48	0	0	1
54	1	0	1
75	0	0	1

Total Number of Saplings in Valley Oak Stand 18



Plot_Number	LO_Saplings	BO_Saplings	VO_Saplings
1	20	0	0
8	0	0	8
15	0	0	10
19	0	0	21
30	0	0	72
64	3	0	0
69	1	0	1



Plot_Number	LO_Saplings	BO_Saplings	VO_Saplings
12	6	0	0
17	1	0	2
25	4	0	2

Appendix 5: UTM Locations for Plots Sampled

StandNumber	StandType	PlotNumber	Date Sampled	UTM-X	UTM-Y	Strata
5	BO	4	3/16/2008	573266.12	4137418.36	Trees
5	BO	9	3/16/2008	573257.98	4137425.25	Trees
5	BO	14	3/16/2008	573266.42	4137444.2	Trees
5	BO	29	3/16/2008	573238.23	4137468.45	Adjacent
5	BO	66	3/22/2008	573219.94	4137544.14	Grass
5	BO	67	3/22/2008	573211.92	4137540.62	Grass
5	BO	69	3/22/2008	573192.92	4137527.65	Grass
5	BO	60	3/22/2008	573198.43	4137506.84	Grass
5	BO	59	3/22/2008	573204.49	4137511.84	Grass
5	BO	57	3/22/2008	573222.21	4137519.62	Grass
5	BO	50	3/22/2008	573210.32	4137491.55	Adjacent
5	BO	54	3/22/2008	573212.75	4137502.08	Grass
5	BO	55	3/22/2008	573201.17	4137501.02	Grass
5	BO	46	3/22/2008	573242.11	4137515.05	Adjacent
5	BO	47	3/22/2008	573232.68	4137504.9	Adjacent
5	BO	49	3/22/2008	573216.08	4137496.54	Adjacent
5	BO	30	3/22/2008	573230.7	4137457.09	Adjacent
5	BO	36	3/22/2008	573249.97	4137495.83	Adjacent
5	BO	38	3/22/2008	573236.3	4137483.13	Adjacent
5	BO	70	3/22/2008	573185.24	4137521.29	Grass
9/10b	VO	30	3/25/2008	572799.8	4137327.52	Adjacent
9/10b	VO	35	3/25/2008	572785.76	4137330.62	Adjacent
9/10b	VO	34	3/25/2008	572783.21	4137347.41	Adjacent
9/10b	VO	10	3/25/2008	572870.86	4137257.28	Trees
9/10b	VO	20	3/25/2008	572851.61	4137244.71	Trees
9/10b	VO	24	3/25/2008	no gps coverage	no gps coverage	Trees
9/10b	VO	40	3/25/2008	572776.58	4137342.61	Adjacent
9/10b	VO	53	4/5/2008	572753.75	4137324.66	Grass
9/10b	VO	54	4/5/2008	572750.6	4137313.7	Grass
9/10b	VO	2	4/5/2008	no gps coverage	no gps coverage	Trees
9/10b	VO	6	4/5/2008	no gps coverage	no gps coverage	Trees
9/10b	VO	13	4/5/2008	no gps coverage	no gps coverage	Trees
9/10b	VO	8	4/5/2008	no gps coverage	no gps coverage	Trees
9/10b	VO	3	4/5/2008	no gps coverage	no gps coverage	Trees
9/10b	VO	43	4/5/2008	572775.76	4137263.12	Adjacent
9/10b	VO	22	4/5/2008	572851.27	4137288.36	Trees
9/10b	VO	17	4/5/2008	no gps coverage	no gps coverage	Trees
9/10b	VO	45	4/5/2008	572783.58	4137311.05	Adjacent
9/10b	VO	48	4/5/2008	572772.76	4137296.8	Adjacent

StandNumber	StandType	PlotNumber	Date Sampled	UTM-X	UTM-Y	Strata
9/10b	VO	42	4/5/2008	572778.68	4137277.71	Adjacent
9/10b	VO	60	4/5/2008	572738.55	4137307.18	Grass
9/10b	VO	75	4/5/2008	57272	4137273.18	Grass
9/10b	VO	74	4/5/2008	572712.8	4137306.38	Grass
Stand 2/3	LO	25	30-Mar-08	573334	4137902	Trees
Stand 2/3	LO	27	14-Mar-08	573334	4137932	Adjacent
Stand 2/3	LO	28	14-Mar-08	573331	4137922	Adjacent
Stand 2/3	LO	30	19-Mar-08	573324	4137904	Adjacent
Stand 2/3	LO	31	30-Mar-08	573328	4137945	Adjacent
Stand 2/3	LO	36	30-Mar-08	573318	4137947	Adjacent
Stand 2/3	LO	38	30-Mar-08	573312	4137929	Adjacent
Stand 2/3	LO	43	30-Mar-08	573302	4137932	Adjacent
Stand 2/3	LO	44	30-Mar-08	573299	4137923	Adjacent
Stand 2/3	LO	45	30-Mar-08	573296	4137913	Adjacent
Stand 2/3	LO	46	30-Mar-08	573299	4137954	Adjacent
Stand 2/3	LO	52	19-Mar-08	523287	4137948	Grass
Stand 2/3	LO	56	19-Mar-08	573280	4137960	Grass
Stand 2/3	LO	57	30-Mar-08	573277	4137950	Grass
Stand 2/3	LO	58	30-Mar-08	573274	4137941	Grass
Stand 2/3	LO	60	30-Mar-08	573268	4137922	Grass
Stand 2/3	LO	62	30-Mar-08	573268	4137954	Grass
Stand 2/3	LO	65	30-Mar-08	573259	4137925	Grass
Stand 2/3	LO	68	30-Mar-08	573255	4137947	Grass
Stand 2/3	LO	70	30-Mar-08	573249	4137929	Grass
Stand 2/3	LO	74	30-Mar-08	573243	4137941	Grass
4	BO	2	4/11/2008	573360	4137806	Trees
4	BO	10	4/11/2008	573381	4137783	Trees
4	BO	13	4/11/2008	573360	4137784	Trees
4	BO	31	4/11/2008	573324	4137759	Adjacent
4	BO	33	4/11/2008	573341	4137749	Adjacent
4	BO	34	4/11/2008	573350	4137745	Adjacent
4	BO	40	4/11/2008	553353	4137731	Adjacent
4	BO	44	4/11/2008	573340	4137727	Adjacent
4	BO	35	4/12/2008	573358	4137740	Adjacent
4	BO	52	4/11/2008	573313	4137719	Grass
4	BO	58	4/11/2008	573317	4137706	Grass
4	BO	61	4/11/2008	573295	4137706	Grass
4	BO	63	4/11/2008	573313	4137697	Grass
4	BO	66	4/11/2008	573290	4137678	Grass
4	BO	69	4/11/2008	573316	4137684	Grass
6/6VO	VO	33	4/13/2008	573047	4137688	Adjacent
6/6VO	VO	34	4/13/2008	573039	4137694	Adjacent
6/6VO	VO	39	4/13/2008	573047	4317702	Adjacent
6/6VO	VO	44	4/13/2008	573053	4137709	Adjacent
6/6VO	VO	48	4/13/2008	573067	4137709	Adjacent
6/6VO	VO	56	4/13/2008	573096	4137709	Grass

StandNumber	StandType	PlotNumber	Date Sampled	UTM-X	UTM-Y	Strata
6/6VO	VO	59	4/13/2008	573074	4137730	Grass
6/6VO	VO	61	4/13/2008	573102	4137716	Grass
6/6VO	VO	68	4/13/2008	573095	4137737	Grass
6/6VO	VO	75	4/13/2008	573088	4137758	Grass
27	BO	5	4/5/2008	571740	4136934	Trees
27	BO	14	4/5/2008	571719	4136927	Trees
27	BO	21	4/5/2008	5717698	4136923	Trees
27	BO	23	4/5/2008	571684	413932	Trees
27	BO	27	4/5/2008	571682	4136921	Adjacent
27	BO	38	4/5/2008	571677	4136900	Adjacent
27	BO	41	4/5/2008	571655	4136907	Adjacent
27	BO	49	4/5/2008	571669	4136878	Adjacent
27	BO	52	4/5/2008	571648	4136887	Grass
27	BO	60	4/5/2008	571664	4136857	Grass
27	BO	68	4/5/2008	571635	4136858	Grass
27	BO	69	4/5/2008	571641	4136852	Grass
18	VO	1	4/5/2008	572026	4136665	Trees
18	VO	8	4/5/2008	572040	4136675	Trees
18	VO	15	4/5/2008	572057	4136690	Trees
18	VO	19	4/5/2008	572061	4136680	Trees
18	VO	30	4/5/2008	572086	4136699	Adjacent
18	VO	40	4/5/2008	572103	4136672	Adjacent
18	VO	46	4/5/2008	572106	4136628	Adjacent
18	VO	47	4/5/2008	572109	4136635	Adjacent
18	VO	52	4/5/2008	572119	4136633	Grass
18	VO	64	4/5/2008	572142	4136641	Grass
18	VO	66	4/5/2008	572141	4136611	Grass
18	VO	69	4/5/2008	572153	416638	Grass
23	LO	27	3/16/2008	571436	4136623	Adjacent
23	LO	30	3/16/2008	571406	4136623	Adjacent
23	LO	31	3/16/2008	571445	4136634	Adjacent
23	LO	33	3/16/2008	571425	4136634	Adjacent
23	LO	34	3/16/2008	571415	4136632	Adjacent
23	LO	36	3/16/2008	571445	4136644	Adjacent
23	LO	39	3/16/2008	571414	4136644	Adjacent
23	LO	45	3/16/2008	571404	4136652	Adjacent
23	LO	48	3/16/2008	571425	4136661	Adjacent
23	LO	50	3/16/2008	571404	4136664	Adjacent
23	LO	51	3/16/2008	571444	4136673	Grass
23	LO	54	3/16/2008	571414	4136672	Grass
23	LO	57	3/16/2008	571435	4136681	Grass
23	LO	61	3/16/2008	571445	4136691	Grass
23	LO	65	3/16/2008	571405	4136693	Grass
23	LO	67	3/16/2008	571436	4136702	Grass
23	LO	71	3/16/2008	571444	4136713	Grass
23	LO	73	3/16/2008	571424	4136710	Grass

StandNumber	StandType	PlotNumber	Date Sampled	UTM-X	UTM-Y	Strata
23	LO	74	3/16/2008	571416	4136708	Grass
23	LO	75	3/16/2008	571405	4136711	Grass
23	LO	24	4/5/2008	571415	4136612	Trees
23	LO	20	4/5/2008	571405	4136603	Trees
23	LO	14	4/5/2008	571401	4136607	Trees
23	LO	3	4/5/2008	571425	4136571	Trees
20	LO	74	3/18/2008	572231.76	4163911.87	Grass
20	LO	72	3/18/2008	572291.35	4136849.21	Grass
20	LO	71	3/18/2008	572288.44	4136865.45	Grass
20	LO	67	3/18/2008	572229.38	4136853.98	Grass
20	LO	66	3/18/2008	572307.33	4136858.05	Grass
20	LO	63	3/18/2008	572309.34	4136846.58	Grass
20	LO	61	3/18/2008	572301.46	4136868.05	Grass
20	LO	57	3/18/2008	572316.82	4136857.92	Grass
20	LO	54	3/18/2008	572333.07	4136842.68	Grass
20	LO	53	3/18/2008	572328.77	4136850.43	Grass
20	LO	1	3/15/2008	572420.19	4136894.35	Trees
20	LO	4	3/15/2008	572420.19	4136665.88	Trees
20	LO	50	3/18/2008	572342.12	4136833.08	Adjacent
20	LO	47	3/18/2008	572335.79	4136862.14	Adjacent
21	VO	75	4/6/2008	572414.41	4137163.33	Grass
21	VO	31	4/6/2008	572444.37	4137079.62	Adjacent
21	VO	34	4/6/2008	572435.12	4137091.09	Adjacent
21	VO	37	4/6/2008	572435.12	4131091.09	Adjacent
21	VO	39	4/6/2008	572403.31	4137093.53	Adjacent
21	VO	25	4/6/2008	572403.32	4137065.99	Trees
21	VO	17	4/6/2008	572430.51	4137048.04	Trees
21	VO	12	4/6/2008	572429.74	4137040.55	Trees
20	LO	8	4/20/2008	572417.78	4136864.89	Trees
20	LO	9	4/20/2008	572417.86	4136862.88	Trees
20	LO	10	4/20/2008	573420.22	4136853.89	Trees
20	LO	15	4/20/2008	572420.78	4136853.1	Trees
20	LO	16	4/20/2008	572392.24	4136852.75	Trees
20	LO	17	4/20/2008	no gps coverage	no gps coverage	Trees
20	LO	18	4/20/2008	5723967.28	4136872.76	Trees